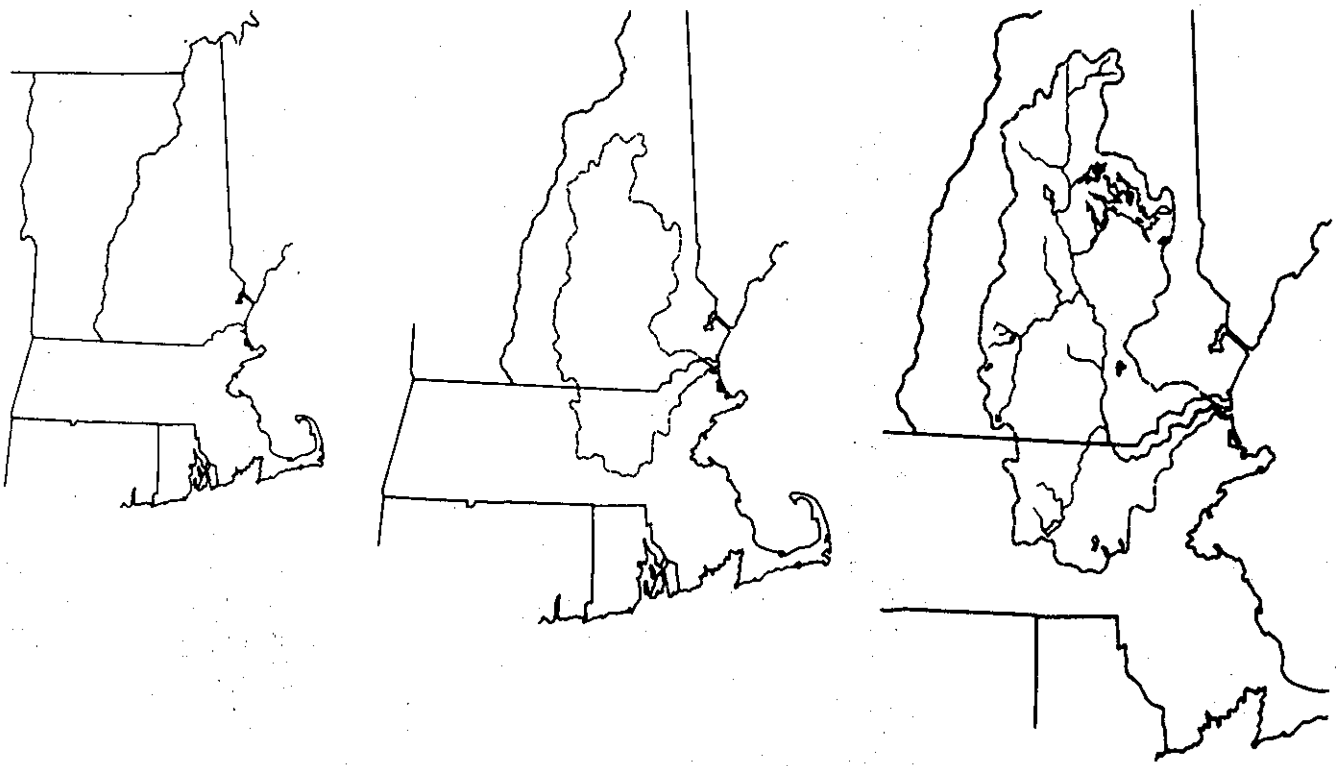
THE MERRIMACK: DESIGNS FOR A CLEAN RIVER
NORTHEASTERN UNITED STATES WATER SUPPLY STUDY



APPENDIX I
BACKGROUND INFORMATION

ANNEX I-A
(Geologic-Hydrogeologic Investigations)

JUNE 1974

MERRIMACK WASTE WATER

MANAGEMENT STUDY

GEOLOGIC-HYDROGEOLOGIC INVESTIGATIONS

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SECTION I - SCOPE OF STUDY

MERRIMACK WASTEWATER MANAGEMENT STUDY

GEOLOGIC-HYDROGEOLOGIC INVESTIGATIONS

I. SCOPE OF STUDY

A. GENERAL

As part of the procedures for evaluating the possibilities of utilizing Land Applications as an alternative method for treatment of wastewater, geologic and hydrogeologic investigations were conducted in the study area. The scope of the investigations may be summarized as follows:

1. To prepare from available data, surficial geology, bedrock geology, and groundwater resources maps for an area designated as the Massachusetts portion of the Merrimack River Basin. Such maps together with their accompanying texts are to depict the nature, occurrence and extent of rock, soil, and groundwater units within the Basin.

2. To prepare from available data, surficial geology, bedrock geology, and groundwater resources maps for the five Regional Planning Agency areas located within the Merrimack Basin (Massachusetts Portion). These maps, with accompanying texts, are to depict the nature, occurrence, and extent of rock, soil, and groundwater units within each area.

3. To visit, examine, and explore 20 selected sites within the Merrimack Basin Area. Based on these examinations, as well as on available data, a report detailing geologic and hydrogeologic findings is to be presented for each site. Comments on the suitability of the sites for wastewater treatment by land methodologies are to be presented.

A total of 21 maps are presented with this report. These include a bedrock geology, surficial geology, and groundwater geology map for each of the five RPA areas; a bedrock geology, surficial geology, and groundwater geology map for the entire Merrimack Basin (Massachusetts portion), and three index maps showing the sources of information used in this study. The following text is intended as explanation for each of these maps. In addition twenty reports, one for each of the twenty selected sites, are included.

It is noted that the consideration of the Land Application method for treatment of wastewater from an agronomic point of view is considered in another separate section of this report.

SECTION II - PROCEDURE USED

II. PROCEDURES USED

A. GENERAL

The procedures used to complete the project involved the assimilation, reduction, and interpretation of existing and available information, as well as the collection of new data resulting from visual examination and exploration of the 20 sites within the study area.

1. Basis of Mapping

Three basic types of information were sought: bedrock geology, surficial geology, and ground water geology of the Basin Area. As will be discussed later, the sources for this information proved to be widely varied. The data obtained differed as to agencies and uses for which it was intended. Furthermore, the types of information which became available contrasted greatly both in their method of description and manner of presentation. Thus, in order to utilize as much of this information as possible, a set of criteria identifying and grouping similarities among the various data was sought. In the case of the surficial geology maps, the criteria established are qualitative, i.e. based on the characteristics of the surficial materials found within the study area. Bedrock geology maps are unit arranged: that is they are organized by rock units and formations of a stated geologic horizon. Ground water data are presented in quantitative terms; i.e., as areas shown as highly favorable, favorable, and unfavorable to ground water development. It should be added that the ground water data, above all others, are highly tentative. Due to the scarcity of available ground water information, we have been forced to extensively interpret existing surficial geology data.

2. Preparation of Site Reports

As part of the geological investigations for the project an inspection was made of 20 sites selected by the Corps of Engineers for further review. The objective of these site visits was to determine in a preliminary way the suitability of these selected sites for waste water treatment. The scope of the assignment limited our site evaluation to use of available data, as well as to a surficial reconnaissance of the site. No allowance was made for making test borings or test pits and no allowance was made for laboratory testing of the on-site materials during this phase of the work. However, when data were available from other sources they were utilized.

The data available consisted of U.S.G.S. Topographic Maps, as well as various geological reports and Soil Conservation Service Maps covering the various sites. These sources of information are shown on the index map which accompanies the geological reports and maps prepared for this project. In addition to these sources of information on several of the sites, Goldberg-Zoino & Associates, Inc. had information such as laboratory soil tests taken on abutting or nearby sites. This information was used to the extent practical.

The ultimate goal of the on-site inspection was to formulate a preliminary opinion on the suitability of the sites for waste water treatment. The three methods considered were spray irrigation (S.I.), overland runoff (O.R.), and rapid infiltration (R.I.). Evaluation of the soils in terms of limitations imposed by various soil groups as well as the index criteria for the soil groups are contained in the groupings made available by the Soil Conservation Service, participants in the study. These criteria, as well as the technical criteria for waste water treatment in terms of geology and soil suitability are contained in Section E.

B. BEDROCK GEOLOGY MAPS

1. Sources of Information

Information used in mapping bedrock units was derived primarily from one source, that being U.S. Geological Survey publications. Maps included in U.S.G.S. Bulletins were most useful, but of those only one, B.K. Emerson's Geology of Massachusetts and Rhode Island, presented information on the entire study area. Other Bulletins provided detailed data on portions of the study area and three mapped U.S.G.S. Bedrock Geology Quadrangles are partially located within the area. Several outside sources such as Billings' Geology of New Hampshire, were utilized in efforts to obtain up-to-date correlations for the various bedrock units. All source information was photo-reduced or photo-enlarged to the Area originals issued (1:48,000).

Attempts to isolate, identify, and correlate rock units in the study area were considerably more difficult than the similar tasks undertaken for surficial units. It quickly became apparent that individual geologists who had worked within the study area differed greatly in their interpretations of the age, sequence, structure, and even composition of the various rock units. For instance, it is not unusual to find two or more names applied to the same rock unit, nor is it a rare occurrence to find that several rock units classified and named by a given author have been lumped together by another writer. A summary of the ages, sequences, and names of the bedrock formations used by various authors for rock units in the study area follows in Table 1.

As may be seen on the preceding table, recent studies have identified significant differences in the relationships among the bedrock units. Those found by Nelson in the Natick Quadrangle, and those mentioned in the 1973 Annual Report of the USGS - DPW Cooperative Program are particularly important. Obviously age and structural relations in the study area are now considered to be quite different from those mapped by earlier workers.

TABLE 1

AGES, SEQUENCES AND NAMES OF BEDROCK FORMATIONS FROM EXISTING LITERATURE

GEOLOGIC AGE		AUTHOR, REFERENCE DATE →	EMERSON Geology of MA & RI Bulletin 597 (USGS) 1917	CLAPP Geol. of the Igneous rocks of Essex Co. 1920	LAFORGE Geol. of the Boston Area Bulletin 839 (USGS) 1932	HANSEN Geol. & Mineral Resources of the Hudson/Maynard Quad. Bull. 1038 (USGS) 1956	BILLINGS Geol. of N.H. N.H. Dept. of Resources & Econ. Devol. 1956
MESOZOIC		TRIASSIC		Diabase Dikes		? Basic Dikes	
PALEOZOIC	LATE	PERMIAN	Hubbardston Gra. Fitchburg Gra. Dracut Dio. ≈ Ayer Gra. Andover Gra. ≈ Straw Hollow Dio.	Andover Gra. Dracut Dio. Beverly Syen.	?Andover Gra. Ayer Granite Fitchburg Gra.	Acton Gra. Ayer Gra. Straw Hollow Dio. Assabet Qtz. Dio.	
PALEOZOIC	LATE	Carboniferous: PENNSYLVANIAN	Bolton Gneiss Brimfield Sch. Worcester Phy. Boylston Sch. Harvard Congl.	Merrimack Qtz.		Gospel Hill Gneiss Nashoba FM	Worcester Phyll. includes Brimfield Schist & Harvard Conglomerate
PALEOZOIC	MIDDLE	Carboniferous: MISSISSIPPIAN	Paxton Qtz. Sch. Oakdale Qtz. ≈ Merrimack Qtz. Beverly Syen. Mattapan Volc.		Cambridge Slate ?Roxbury Congl. Brighton Melaphyre Worcester FM. Merrimack Qtz.	Worcester FM includes Brimfield Schist & Harvard Conglomerate	?Quincy Gra
PALEOZOIC	MIDDLE	DEVONIAN	Ironstone Qtz. Dio. Milford Gra. Dedham Granodio. Newburyport Qtz. Dio. Salem Gabb. Dio. Newbury Volc.	Lynn Volcanics Dedham Granodio. Newburyport Qtz Dio Salem Gabb Dio	?Quincy Gra. ?Newbury Volc. Mattapan Volc.	?Dedham Granodio. Salem Gabb. Dio.	Andover Gra. Ayer Granodio. ?Fitchburg Gra. Dracut Dio. Newbury Volc.
PALEOZOIC	MIDDLE	SILURIAN					?Merrimack Group includes Oakdale quartzite & various gneiss & sch.
PALEOZOIC	EARLY	ORDOVICIAN			Milford Gra. Dedham Granodio. ?Newburyport Qtz. Dio. Salem Gabb. Dio.		
PALEOZOIC	EARLY	CAMBRIAN			Waltham Gneiss = part of gneisses & schists of undt. age		Milford Gra. Dedham Granodiorite
PRE-CAMBRIAN			Marlboro FM ? Westboro Qtz.	Metamorphic sedimentary ? rocks at Nahant	Marlboro FM Westboro Qtz.	?Marlboro FM	?Newburyport Qtz. Dio. Marlboro FM. Westboro Qtz.

TABLE 1

AGES, SEQUENCES AND NAMES OF
BEDROCK FORMATIONS
FROM EXISTING LITERATURE

GEOLOGIC AGE / AUTHOR / REFERENCE / DATE		TOULMIN Bedrock Geol. of Salem Quad. Bulletin 1163-A (USGS) 1964	JAHNS, WILLARD WHITE, et.al. Prelim. Bedrock Geol. of Lowell-Westford Area USGS open file 1959	NELSON Prelim. Bedrock Geol. Map of Natick Quad. USGS open file 1973	VOLCKMAN Prelim. Bedrock Geol. Map of Holliston Quad. USGS open file 1973	BELL, et. al. in USGS/DPW Coop. Program Annual Report June 1973
MESOZOIC	TRIASSIC	? Diabase	Diabase dikes			
PALEOZOIC – LATE	PERMIAN	Beverly Syenite	Andover Gra. Acton Gra. Ayer Gra. Dracut Norite			
PALEOZOIC – LATE (Carboniferous)	PENNSYLVANIAN		Nashoba FM			
PALEOZOIC – LATE (Carboniferous)	MISSISSIPPIAN		Worcester FM includes Brimfield Schist & Harvard Conglomerate	Cambridge Slate Roxbury Congl. Brighton Metaphyre		
PALEOZOIC – MIDDLE	DEVONIAN		?Merrimack Qtz. includes "Chelmsford Granite"	Mattapan Volc.	Milford Gra. Dedham Granodio.	Cape Ann Plutonic Series Beverly Syenite et. al.
PALEOZOIC – MIDDLE	SILURIAN	Newbury FM			Marlboro FM	Andover Gra. et al
PALEOZOIC – EARLY	ORDOVICIAN			Dedham Granodio Cherry Brook FM Kendal Volc.		Nashoba FM Marlboro FM
PALEOZOIC – EARLY	CAMBRIAN	?Newburyport Qtz. Dio. Salem Gabb.Dio.		Westboro FM Rice FM	Westboro Qtz.	Dedham Granodio.
PRE-CAMBRIAN		?Marlboro? FM				Marlboro FM (part) Westboro Qtz.

2. Explanation of Legend and Mapping Procedures

Considering all the available information, a partial map illustrating the distribution and extent of rock units mapped by modern workers could be prepared. Or, on the other hand, a complete map showing the location and occurrence of rock units for the entire study area could be taken from the early study which encompassed this area; i.e. Emerson's 1917 map in Bulletin 597. It would be impossible to completely reconcile the two contrasting sets of data and yet maintain the meaning and intent of either. We have chosen the latter course of action, that being to use Emerson's work as the basis for our mapping. His bedrock units within the Merrimack Basin have been divided into two groups: 1) Igneous Rocks, and 2) Sedimentary and Meta-Sedimentary Rocks. Within these groups Emerson's descriptions and names have been used for the various rock units identified and mapped. More recent information has been added to the maps whenever it was sufficiently extensive so as to provide continuity among the mapped units. These data include new names applied to some of Emerson's unnamed formations, additional rock units identified by modern workers in certain areas, and regrouped or "lumped" rock units that today are thought to be of similar composition and relationships (age/structure). A summary of geologic materials used on the Bedrock Geology maps for this study follows in Table 2 (Part A- Igneous Rock, and Part B- Sedimentary, Meta-Sedimentary Rocks). Six bedrock maps were prepared: one for each of the five RPA Areas (Figures B1-B5) and one for the basin as a whole (Figure B6).

C. SURFICIAL GEOLOGY MAPS

1. Sources of Information

The sources of available information from which the surficial geology maps were prepared include: U.S. Geological Survey Surficial Geology Maps (7-1/2 minute quadranges); Surficial Geology Maps in U.S. Geological Survey and Massachusetts DPW Bulletins (of various sizes and scales); Surficial Geology Maps and "materials" maps in U.S. Geological Survey Water Supply Papers (of various sizes and scales); Soil maps in U.S. Department of Agriculture Publications (SCS maps at 1: 62,500 scale); and U.S. Geological Survey Topographic Maps (7-1/2 minute quadrangles). All source information was photo-reduced or photo-enlarged to the scale of the RPA Area originals issued (1:48,000).

2. Explanation of Legend and Mapping Procedures.

As discussed earlier, these source materials differed greatly in both the manner and intent for which they were written. Thus a simple system was needed for classifying surficial materials which could be used with any of the available data. As it evolved, this system was based on the physical characteristics of the materials present.

The Surficial Geology Legend included here and on Figures S1, S2, S3, S4, S5 and S6 represents that system. Initially the surficial materials

TABLE 2

SUMMARY OF GEOLOGIC MATERIALS
used on
BEDROCK GEOLOGY MAPS

(A - IGNEOUS ROCKS)

File No. 1182
Merrimack Study

SYMBOL	UNIT/FORMATION NAME	AUTHOR	GENERALIZED DESCRIPTION	REMARKS
	DIABASE DIKES		Gray to black dikes, soils & flows - often referred to Triassic Age	
	PEGMATITE BODIES (unassigned)	(Emerson's)		
	BEVERLY SYENITE	Emerson (?)		
	HUBBARDSTON GRANITE	Emerson	Variable, pegmatitic granite, often full of schist inclusions	with inclusions called Ware Schist
	FITCHBURG GRANITE	Emerson	Light colored, muscovite-biotite granite	
	ANDOVER GRANITE	Emerson (?)	Gray, fine to medium grained; occurs with pegmatites	
	STRAW HOLLOW DIORITE & ASSABET QUARTZ DIORITE	Emerson/ Hansen	Medium grained, slightly foliated; may show linear structure	
	ACTON GRANITE	Hansen	Gray, fine grained, foliated	
	AYER GRANITE	Emerson	Complex, gneissic; medium to coarse grained	
	DRACUT DIORITE	Emerson	Variable, gabbro-diorite-norite	
	NEWBURY and MATTAPAN VOLCANICS	Emerson/ LaForge	Varied lavas, lahars, tuffs, breccias; with sedimentaries	
	MILFORD GRANITE	Dale (?)	Pink to gray, medium to coarse grained, foliated	Mapped with Ironstone qtz. diorite
	DEDHAM GRANODIORITE	Emerson	Pink to gray, massive; occurs with quartz diorite	Mapped with Wolfpen tonalite
	NEWBURYPORT QUARTZ-DIORITE	Emerson	Medium grained, massive	
	SALEM GABBRO-DIORITE	Clapp	Variable, fine to coarse grained	
	KENDAL VOLCANICS	Nelson (?)	Gray color, fine grained, thinly laminated volcanic ash	

TABLE 2

SUMMARY OF GEOLOGIC MATERIALS
used on
BEDROCK GEOLOGY MAPS

(B - SEDIMENTARY, METASEDIMENTARY ROCKS)

File No. 1182
Merrimack Study

SYM-BOL	UNIT/FORMATION NAME	AUTHOR	GENERALIZED DESCRIPTION	REMARKS
	GNEISSES and SCHIST (unassigned)	(Emerson's)	Biotitic gneisses & schists - in part igneous origin	Merrimack Qtzite of Billings; also part Waltham Gneiss (LaForge)
	Boston Group			
	CAMBRIDGE SLATE	Emerson (?)	Gray color, fine-grained argillite	
	ROXBURY CONGLOMERATE	Emerson (?)	Gray to pinkish color, coarse-grained cobble conglomerate	
	GOSPEL HILL GNEISS	Hansen	Gray color foliated granite-gneiss	
	NASHOBA FORMATION	Hansen	Gray color biotite gneiss with schist	Includes 'Bolton' gneiss
	BOYLSTON SCHIST	Emerson	Medium-coarse grained, micaceous	
	Worcester Group			
	BRIMFIELD SCHIST	Emerson	Coarse-grained muscovite schist	
	WORCESTER PHYLLITE		Gray color, foliated sandy slate	
	HARVARD CONGLOMERATE	Crosby	Pebble conglomerate with slate layers	
	PAXTON QUARTZ SCHIST	Emerson	Biotitic, quartzitic, gneissoid	Some of the unassigned Gneisses & Schists belong here
	Merrimack Group			
	OAKDALE QUARTZITE	Emerson	Biotitic with calcareous lenses, greatly jointed	
	MERRIMACK QUARTZITE	Hitchcock	Gray slatey quartzite with biotitic schist and quartz schist	
	CHERRY BROOK FORMATION	Nelson (?)	Dark colored gneisses, amphibolites (foliated, layered) tuffs	
	MARLBORO FORMATION	Emerson	Schists with quartzites, amphiboles, gneisses, thinly laminated	
	WESTBORO FORMATION	Emerson	Quartzites - light colored, sorted, medium grained; also schist & phyllite	
	RICE FORMATION	Nelson (?)	Gray, fine to medium grained gneiss with quartzite	

are divided into two groups: 1) coarse-grained soils and 2) fine-grained and/or organic soils. These distinctions are primarily defined by each group's grain-size properties; however, other sets of physical and engineering properties are closely related (i. e., dry unit weight, water content, plasticity, permeability, void ratio, consolidation properties, etc.) Further divisions within each group are made; these subgroups may also be associated with certain physical and/or engineering properties. Some of the subgroups may be further assigned to a geologic genesis such as "ice-contact" deposits, or to a specific landform such as a kame or an esker. However, in many instances the surficial materials within one subgroup may have occurred via a variety of geologic processes and/or exist in several landforms. It was considered of importance here that, regardless of origin or landform, the materials classified within a given group or subgroup have similar specific and definable properties.

Once the surficial geology legend was established, reduction of the available data began. A priority of source information was established. This amounted to selecting as "prime" data sources that information which was most closely associated with, and easily converted to, the groupings represented in our classification system (legend). Modern U.S.G.S. Surficial Geology Quadrangles were selected as prime data sources. Twelve quadrangles were so used including three open-file reports not yet in print. Where information was not available on surficial quadrangle maps, other U.S.G.S. and D.P.W. reports were utilized. These included a variety of older out-of-print publications, modern day water supply papers and unpublished open-file reports from various agencies. U.S. Department of Agriculture soils maps were utilized in areas where no other surficial information was available. These included parts of Worcester, Middlesex, and Essex Counties. The publications belonged to older series, 1922, 1924 and 1925 vintage. In all instances interpretations of these soil maps were required. This was done using text descriptions of the soils and their origins, then plotting the locations and extent of the deposits on modern day U.S.G.S. topographic maps. Where obviously needed, minor adjustments in the location of the soil deposits were made. Swamps and inferred swamp deposits were traced directly from U.S.G.S. topographic maps.

D. GROUND WATER GEOLOGY MAPS

1. Sources of Information

Ground water maps for the Merrimack River Basin given in this report are transfers of ground water favorability maps completed by the U.S. Geological Survey (USGS) or extrapolations of the groundwater-surficial geology relationships indicated in areas mapped by both methods to those where only the surficial geology mapping is completed. The Geological Survey has completed ground water favorability estimates in only one drainage basin within the Merrimack Basin proper, the Assabet (See Figure I-3), and two in adjoining drainage basins have been published (the Parker-Rowley and Ipswich basins). Several

TABLE 3

SUMMARY OF MATERIALS USED
on
SURFICIAL GEOLOGY MAPS

File No. 1182
RE: MERRIMACK STUDY

	SYMBOL used on PLANS	DEPOSITS	ORIGIN (Transportational and/or Depositional Agent)	REPRESENTATIVE LAND FORMS	MATERIAL DESCRIPTION
Coarse-Grained Soils		Glacio-fluvial Glacio-lacustrine (stratified drift; outwash and ice contact)	via Glacial streams	Outwash Plains, Kame Terraces, Kames, Eskers, Crevasse Fillings; Kame deltas, Esker deltas	SANDS or SANDS & GRAVELS; Silt and/or Clay portions usually minor - may include cobbles--stratified, moderate to well sorted.
Coarse-Grained Soils		Glacio-marine Dune deposits	Reworked glacial & stream deposits-via tidal action, currents; wind blown	Marine terraces, Marine plains, Dunes, Beaches, Bars	Primarily fine or fine to medium SANDS well sorted - often stratified and cross-bedded.
Coarse-Grained Soils		Alluvium & River Terrace deposits	via Recent rivers and streams	Flood plains, Alluvial terraces, Alluvial flats, Alluvial fans, stream terraces	SAND, SILT, with minor amounts of Gravel and/or Clay - poorly to moderately sorted and stratified.
Coarse-Grained Soils		Glacial Till (non-stratified drift deposits)	Subglacial, Superglacial (Lodgement & Ablation), Flow till	Ground Moraine, End Moraine, Drumlins, Slumped/Flow structures	Silty or Clayey SANDS & GRAVELS with cobbles and boulders - generally dense, non-stratified, unsorted mixture; locally variable.
Fine-Grained and/or Organic Soils		Glacio lacustrine (stratified drift)	via Glacial streams into glacial lake bottoms	Lake basins, Lake beds	SILTS, Clayey SILTS, Silty SANDS, varved Silts and Clays.
Fine-Grained and/or Organic Soils		Glacio-Marine	via Glacial streams into offshore marine environment	Marine plains, marine terraces	Silty CLAYS, SILTS and CLAYS, SILTS, Silty fine SANDS.
Fine-Grained and/or Organic Soils		Fresh water Organic deposits	Eutrophication of ponds, lakes, etc.	Kettle holes, morainal depressions, lake basins, river meanders	PEATS, Sandy PEATS, Silty PEATS, Organic Sands or Silts, "Muck".
Fine-Grained and/or Organic Soils		Marine Organic deposits	Accumulation of organic detritus associated with the flooding of coastal plains	Estuaries, tidal marsh and mud flats; river mouths	ORGANIC SILTS, Clayey Organic Silts, Organic Sands, Marsh Mats, "Ooze", "Muck".

special studies of small areas within the Basin have also been published (Perlmutter, 1962; Hartwell, 1970), and regional evaluations of the potential for buried river channel deposits as high volume aquifers are available (Allen, et al, 1952; Howard, 1967). These supplement the ground water favorability maps by Pollock, et al (1969) for the Assabet, Sammel (1967) for the Parker-Rowley, and Sammel, et al, (1966) for the Ipswich, but very little else in terms of potential for development of ground water supplies is in published form.

In addition to published information, basic ground water information for the Merrimack River Basin (primarily well logs) is maintained in the files of the Ground Water Branch of the Geological Survey in Boston, Massachusetts. An early attempt to evaluate these logs for the study was made, but the number of logs and variable quality of the data indicated that such an effort would require considerably more time than was available for the project. These logs are currently being evaluated for drainage basins within the Merrimack by the USGS and at least one additional ground water favorability map should be published in the near future. Some published data concerning the quality of water within the basin is also available; no effort to evaluate water quality was undertaken for this report.

2. Explanation of Legend and Mapping Procedure

Because of the rather limited amount of ground water data available, an alternate method of mapping ground water favorability within the Merrimack River Basin was selected. A comparison of areas mapped by the USGS in the Assabet basin as having potential for moderate yield wells (see below) with areas on the surficial geology maps denoted as stratified drift deposits (Figures W1 through W6) showed near one-to-one correspondence of the map units. This correspondence was used to map all other parts of the remainder of the Merrimack Basin with a few exceptions.

Mapping units used by the USGS on Ground Water Favorability maps are given as:

A. Areas where most wells will yield less than 25 gallons per minute. The aquifer consists of poorly permeable material, chiefly till and bedrock, but also includes some areas of sand and gravel, the saturated thickness of which is generally less than 25 feet.

B. Areas where yields from properly constructed wells may range from 25 to 75 gallons per minute (also includes some areas whose ground water potential is unknown). In these areas the aquifer consists of sand and gravel, the saturated thickness of which generally is greater than 25 feet.

C. Areas most favorable for the location of wells that may yield more than 75 gallons per minute. This unit generally consists of sand and gravel, the saturated thickness of which is greater than 25 feet. Although yields from wells in these areas may, in places, range as high as 500 gallons per minute, the most common safe yield from properly constructed wells is probably in the 100 to 150 gallons per minute range.

Unit (B) above is mapped for the Assabet basin as given by the completed USGS maps, and is mapped in the remainder of the basin where stratified drift is indicated with the following exceptions:

1. Certain areas indicated as stratified drift have no apparent supply of surface water other than rainfall and no readily identifiable underground source: these areas are mapped under category (A) of the USGS map units and identified in the discussions of the individual Regional Planning Area (RPA) ground water maps.

2. If stratified drift areas were judged to have category (A) of the USGS map units in areas abutting the Merrimack Basin boundaries, the category (A) favorability was carried into the Merrimack Basin with the stratified drift, unless some other factor suggested that category (B) or (C) was indicated: these areas are also pointed out in the individual RPA.

Unit (C) of the USGS ground water favorability is transferred from the completed favorability maps of the Assabet drainage basin directly, and all other category (C) mapping must be considered very subjective. The primary basis for any indication of category (C) outside of the Assabet is if high volume wells(primarily city or industrial supplies) are known. Areas for category (C) are extended from the wells in direction of inferred or known buried river channels with 50 feet or more of fill in the buried channel. Unit (C) must be considered incompletely mapped outside of the Assabet, particularly along river channels and in towns where water supply volumes are not readily available in published form.

E. 20 SITE INVESTIGATIONS

1. General Information

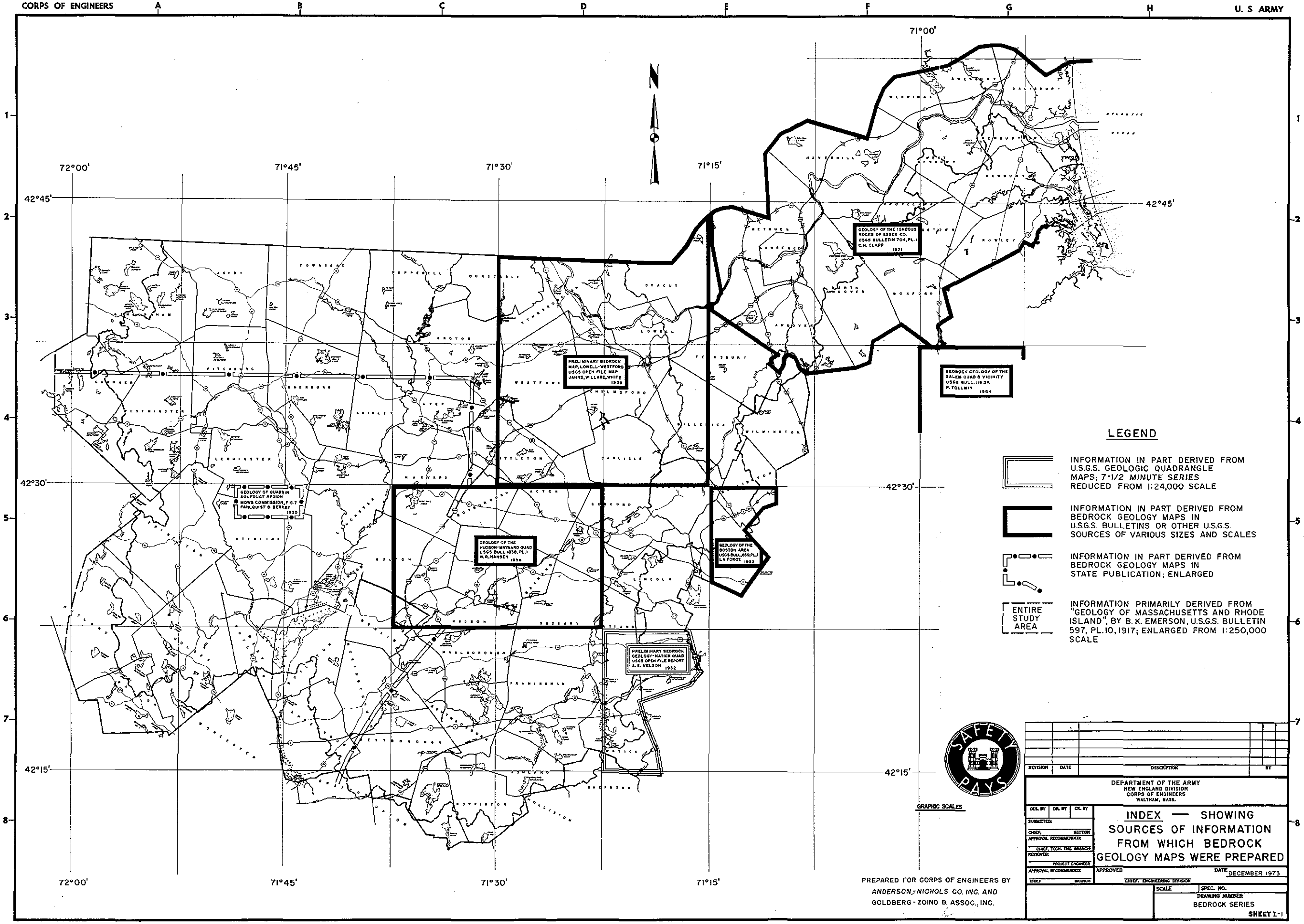
Each of the 20 sites was visited by a principal engineer or senior geologist from Goldberg-Zoino & Associates, Inc. The site visits generally were less than one day in length and consisted of an on-site inspection of the features which could be readily examined. Such features might include bedrock outcrops, presence or lack of stone or boulder fences, excavations for home sites, exposed cuts in roads and railroads, borrow pit operations, presence of poorly drained areas, bodies of water, organic soils and the like. Where possible, hand specimens of the bedrock exposures were returned to the office for further examination by the geologists. In addition to the physical characteristics of the land, observations were made as to the use characteristics of the land, and the general aesthetic appearance of the land when applicable.

In arriving at qualitative evaluations on the suitabilities of the sites for waste water treatment by land methods, certain conflicting criteria sometimes had to be considered on individual sites. For example, some sites which were rated good to fair for rapid infiltration treatment were considered fair, and sometimes poor, for spray irrigation. The principal reason for this usually was that the spray irrigation criteria limited slopes to a range of of zero to 15% and this slope limitation was adhered to as much as practical. However, with site grading and engineering, slopes could be changed to fall within design criteria. It should also be noted that the proposed 50 foot depth to ground water for Group 2 soils for rapid infiltration may be too stringent in the Merrimack River Basin. Accordingly, where permeable soils of the order of 20 feet thick above the water table existed at a site, this was rated a good to fair possibility for rapid infiltration treatment. As noted previously, on-site explorations such as test pits and borings were not made. Consequently a certain degree of conservatism had to be introduced in the site evaluation for waste water treatments shown on Table 4. Nevertheless, with proper site investigation, design and site improvement, many of the areas listed on Table 4 could be upgraded and ultimately utilized for treatment of waste water.

In many cases, definitive information on depth to ground water, depth to bedrock, and character of the soil formations was difficult to obtain because of lack of on-site exposures of these various features. In these cases a guesstimate was made based on the available data and the site visit. A rating system was introduced which included the degree of confidence in the evaluation. A table has been prepared which summarizes the site locations together with the assigned evaluation of the site for waste water treatment in terms of the methods of waste water treatment which have been proposed. This summary is included at Table 4 (Section III-c).

2. Land Treatment Methodologies

The following information has been excerpted from the Department of the Army, Office of Chief Engineers, Memorandum to Division Engineer, New England, 7 February 1972, which included memorandum of 24 January 1972,



CORPS OF ENGINEERS
U. S ARMY
A
B
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1
2
3
4
5
6
7
8
72°00'
71°45'
71°30'
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BEDROCK GEOLOGY OF THE SALEM QUAD & VICINITY USGS BULL.1163A P. TOULMIN 1964
PRELIMINARY BEDROCK MAP, LOWELL-WESTFORD USGS OPEN FILE MAP JAHNS, WILLARD, WHITE 1959
GEOLOGY OF QUABBIN AQUEDUCT REGION MDWS COMMISSION, FIG.7 FAHLQUIST & BERKEY 1935
GEOLOGY OF THE HUDSON-MAYNARD QUAD USGS BULL.1038, PL.I W.R. HANSEN 1956
GEOLOGY OF THE BOSTON AREA USGS BULL.839, PL.I LA FORGE 1932
PRELIMINARY BEDROCK GEOLOGY-NATICK QUAD USGS OPEN FILE REPORT A.E. NELSON 1932
ATLANTIC OCEAN
FITCHBURG
LUNENBURG
LEOMINSTER
WESTMINSTER
STERLING
SHIRLEY
AYER
GROTON
PEPPERELL
TOWNSEND
DUNSTABLE
TYNGSBORO
WESTFORD
CHELMSFORD
LOWELL
DRACUT
TEWKSBURY
BILLERICA
CARLISLE
LITTLETON
HARVARD
BOLTON
ACTON
CONCORD
LINCOLN
HUDSON
SUDBURY
MARLBOROUGH
FRAMINGHAM
WESTBOROUGH
ASHLAND
HOPKINTON
HOLLISTON
SHERBORN
NATICK
WORCESTER
METHUEN
LAWRENCE
ANDOVER
NORTH ANDOVER
BOXFORD
HAVERHILL
MERRIMAC
AMESBURY
SALISBURY
NEWBURY
NEWBURYPORT
ROWLEY
WILMINGTON
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ANDERSON-NICHOLS CO. INC. AND
GOLDBERG-ZOINO & ASSOC., INC.
REVISION
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BY
DEPARTMENT OF THE ARMY
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WALTHAM, MASS.
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DATE DECEMBER 1973
SCALE
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DRAWING NUMBER
BEDROCK SERIES
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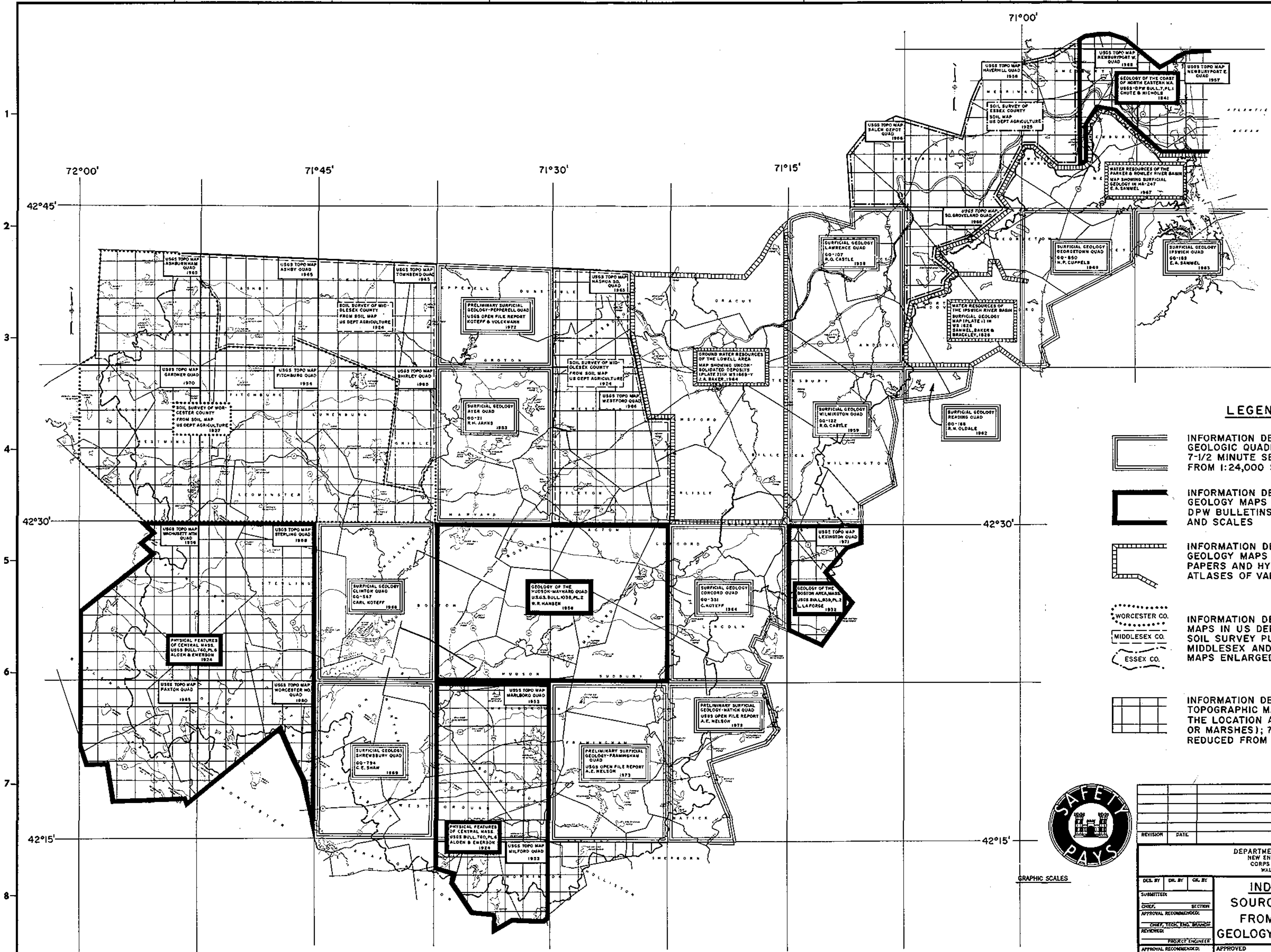

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INFORMATION DERIVED FROM SURFICIAL GEOLOGY MAPS IN U.S.G.S. WATER SUPPLY PAPERS AND HYDROLOGIC INVESTIGATIONS ATLASES OF VARIOUS SIZES AND SCALES

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MIDDLESEX CO.
ESSEX CO.
INFORMATION DERIVED FROM SOILS MAPS IN US DEPT. OF AGRICULTURE SOIL SURVEY PUBLICATIONS (WORCESTER, MIDDLESEX AND ESSEX COUNTIES) MAPS ENLARGED FROM 1:62,500 SCALE

INFORMATION DERIVED FROM U.S.G.S. TOPOGRAPHIC MAPS (PRIMARILY USED TO MAP THE LOCATION AND EXTENT OF SWAMPS OR MARSHES); 7-1/2 MINUTE SERIES, REDUCED FROM 1:24,000 SCALE

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DES. BY | DR. BY | CK. BY

SUBMITTED:
CHIEF, SECTION
APPROVAL RECOMMENDED:
CHIEF, TECH. ENG. BRANCH
REVIEWED:
PROJECT ENGINEER
APPROVAL RECOMMENDED:
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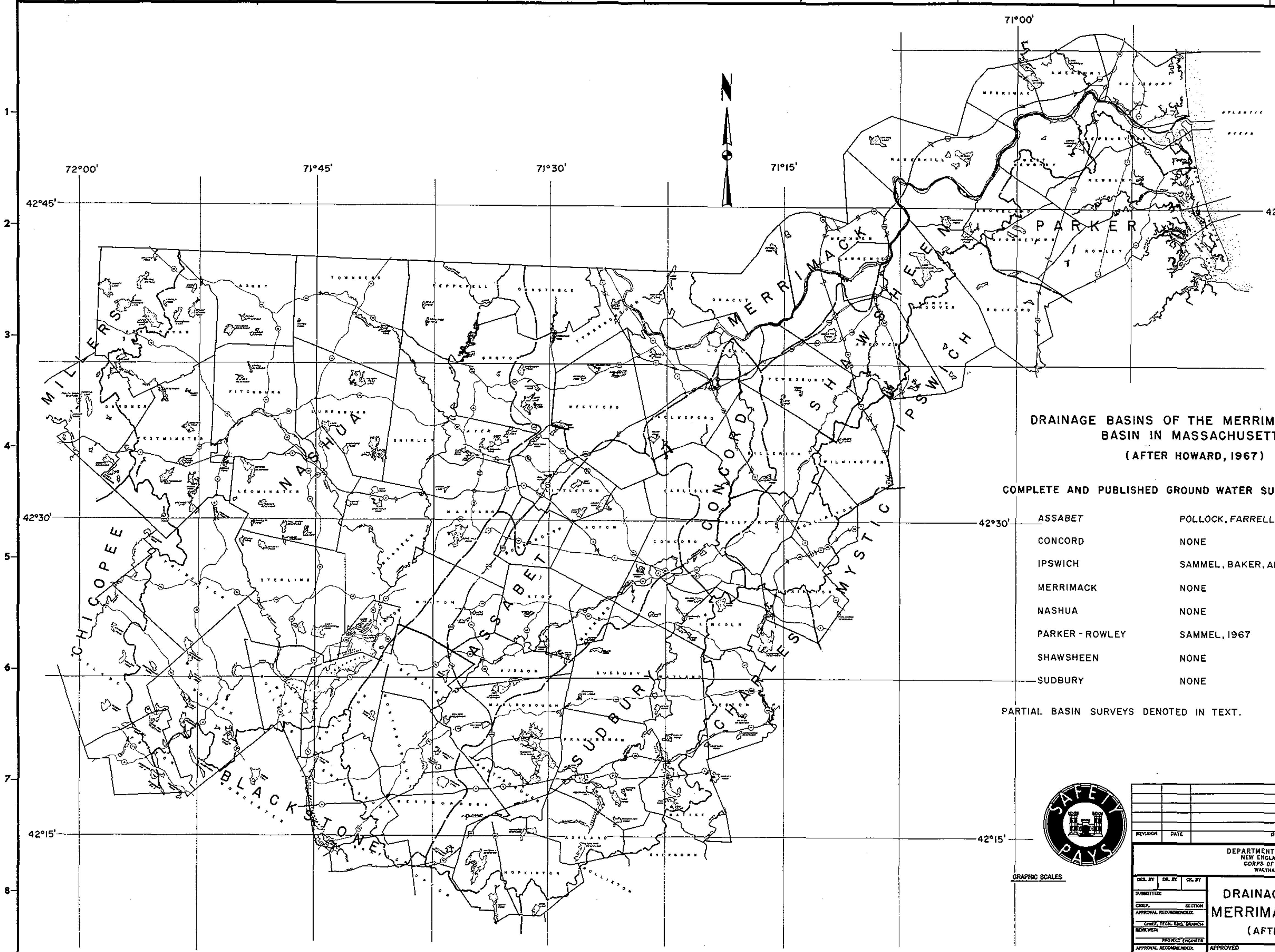

DRAINAGE BASINS OF THE MERRIMACK RIVER BASIN IN MASSACHUSETTS

(AFTER HOWARD, 1967)

COMPLETE AND PUBLISHED GROUND WATER SURVEYS:

ASSABET	POLLOCK, FARRELL, AND CASWELL, 1969
CONCORD	NONE
IPSWICH	SAMMEL, BAKER, AND BRACKLEY, 1966
MERRIMACK	NONE
NASHUA	NONE
PARKER - ROWLEY	SAMMEL, 1967
SHAWSHEEN	NONE
SUDBURY	NONE

PARTIAL BASIN SURVEYS DENOTED IN TEXT.

SAFETY PAYS

GRAPHIC SCALES

PREPARED FOR CORPS OF ENGINEERS BY
ANDERSON - NICHOLS CO. INC. AND
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REVISION	DATE	DESCRIPTION	BY

DEPARTMENT OF THE ARMY
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DES. BY | DR. BY | CK. BY
SUBMITTED
CHIEF, SECTION
APPROVAL RECOMMENDED:
CHIEF, TECH. ENG. BRANCH
REVIEWED:
PROJECT ENGINEER
APPROVAL RECOMMENDED:
CHIEF BRANCH

DRAINAGE BASINS OF THE MERRIMACK RIVER BASIN

(AFTER HOWARD, 1967)

APPROVED
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DATE DECEMBER 1973
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DRAWING NUMBER
GROUND WATER SERIES
SHEET I-3

"Effectiveness and Effects of Land Treatment Methodologies as a Means of Wastewater Treatment".

Optimum Technical Criteria. Following the initial assessment effort, it was possible to define technical criteria for system design and operation. This initial cut at criteria is oriented toward optimum sites/conditions. While guidance can be developed on this border range in time, it is suggested that first-cut criteria along the following lines be issued.

a. Spray Irrigation Criteria- Optimum

Soil textural class- loam to silt loam surface horizons with similar textures throughout underlying strata.

Infiltration capacity of soil surface- a maintained rate of two inches per day minimum.

Effective length of travel of effluent- minimum of six feet of aerobic, free-draining soil (may be obtained through manipulation through addition of soil amendments).

Aerosol buffer zone- continuously vegetated strip with width equal to distance of throw of sprinkler times height of delivery.

Slope- 0 to 15 percent.

Continuous vegetation with periodic harvesting required.

Application- one application per week totaling 2 inches in 8 hour period; however, weekly total rainfall plus waste water addition cannot exceed 4 inches.

-maximum total annual wastewater addition will not exceed 2,500,000 gal/acre. (Note: year round irrigation at 2"/acre/week would equal 2,823,000 gal/acre/year).

-discontinue spraying when surface soil temperatures reach 32°F.

b. Overland Runoff Criteria- Optimum

Soil textural class- clay loam surface horizons.

Infiltration capacity of soil surface- a maintained rate of less than 0.2 inches per day entering the soil and passing a 6-inch depth (thus a surface soil may have considerably greater permeability).

Effective length of travel of effluent- minimum of 300 feet along slope.

b. Overland Runoff Criteria- Optimum (Continued)

Carbon-nitrogen ratio- minimum of 15 (can manipulate).

Slope- 1-1/2 to 6 percent.

Aerosol buffer zone- continuously vegetated strip with width equal to distance of throw of sprinkler times height of delivery.

Continuous vegetation with periodic harvesting recommended.

Application - 3 applications per week, totaling 2 inches, such that weekly total rainfall plus wastewater addition cannot exceed 4 inches.

-discontinue when soil temperatures approach 32°F.
-maximum total waste water addition - 2,500,000 gal/acre/year.

c. Rapid Infiltration Pond Criteria- Optimum

Soil texture class- sand or sandy gravel throughout the path of effluent travel.

Infiltration capacity of soil surface- a maintained 9-12 inches per day minimum.

Effective length of travel of effluent- minimum of 350 feet total vertical plus lateral travel.

Continuous grass vegetation maintained as possible.

Application- 9 to 12 inches per day applied for up to 14 days, alternated with rest period of 7-14 days (with above freezing temperatures).

3. Soil Groups - as established by Soil Conservation Service for use in this study.

The following generalized soil groups describe the conditions for the major kinds of soil in the Massachusetts portion of the Merrimack River Basin.

Group 1

Deep well- to excessively drained sandy loams, and fine sandy loam glacial till soils. Subsoils are usually coarser than the surface material. Stones or gravel are present at 1.5 to 2.0 feet below the surface and in many cases on surface.

Slopes range from three to more than twenty five percent. These soils have rapid (5-10 inches/hour) to very rapid (greater than 10 inches/hour) permeability near the surface. Permeability in the substratum may be slow due to an impervious layer. Water holding capacity is moderate to low, consequently water falling on these soils readily enters the soils, moving rapidly downward through the soil profile.

The rapid permeability and the low moisture holding capacity affects the rate and frequency of irrigation, so plant nutrients are not moved below the root zone. Gloucester, Canton, and Quonset are typical soils in this group which have slight to moderate limitation for wastewater application if the slope is less than 15 percent.

Group 2

Deep, droughty, rapidly permeable, glacial outwash loamy sands, which may contain gravel in the subsoil. Water holding capacity of this soil is low (0.5 inches/foot of depth). About 75 percent of these soils are on slopes of 0 - 15 percent. Soil of the Carver, Hinckley, Merrimack, Warwick and Windsor series are typical of this group and frequently occur in areas of permeability and low water holding capacity, they require special management practices for their use to renovate wastewater. Where the ground water is +50 feet below the surface, rapid infiltration may prove a feasible treatment method for wastewater.

Group 3

Soils developed in glacial till or material underlain by glacial till that have a hard pan or impervious layer at 1.5 to 3.0 feet of the surface. Above the impervious zone these soils are well-to moderately well-drained sandy loams or loams with good water-holding capacity. The impervious layer may vary in thickness from a few inches to several feet, and is moderately slow to slow permeable.

Excess water moving through the solum will be directed laterally along the impervious pan and reappear at the surface creating seep spots on lower slopes.

Soils belonging to the Acton, Bernardston, Birchwood, Broadbrook, Essex, Millis, Narragansett, Paxton, Poquonock, and Scituate series are included in this group. These soils occur on slopes ranging from three to twenty-five percent. Although stones are often present, there are small areas that are free of stones. The soils in this group have moderate limitation if slope is less than 15 percent.

Group 4

Deep, very fine, sandy loams along flood plains of major streams. These soils may have seasonally high water tables or high water tables during prolonged periods of rainfall. Consequently these soils are limited in their utility for treating wastewater. This can be overcome with proper management practices. These soils are well to moderately well drained when the water table is not high. Permeability of these soils is moderate or moderately rapid. Hadley, Ondawa, Podunk, and Winooski series are low bottom soils which are usually flooded every year. Agawam, Buxton, Deerfield, Elmwood, Ninigret, Sudbury, and Tisbury series are soils of higher bottom areas which are seldom flooded but have fluctuating water tables.

Group 5

Deep, well- to moderately well-drained loams and silt loams with moderate or moderately slow permeability. Stones and cobbles may be present. Slopes range from 0 to more than 25 percent. When slopes are less than 15% these soils are highly suitable for wastewater application. Soils belonging to the Belgrade, Brookfield, Charlton, Enfield, Hartland, Melrose, Newport and Suffield series are included in this group.

Group 6

This group consists of shallow soils. They are usually droughty because of the limited depth to bedrock. They occur most often on steep forested slopes of more than 15 percent, and often in large tracts of 300 acres or more. They have severe limitations for waste disposal. These shallow soils account for nearly 20 percent of the area in the Basin. None of the soils in this group has been selected for wastewater or sludge disposal.

Group 7

Poorly drained soils with high water tables seven or more months of the year. These soils have developed in either sands, silts, or glacial till. Infiltration may be rapid, moderate, or slow but due to a high water table the soils are poorly drained. Some soils contain gravel or stones while others do not. Because the water table is high for most of the year these soils are not considered for receiving wastewater or sludge.

Group 7 (Continued)

Soils included in this group belong to the Au Gres, Biddeford, Birdsall, Brockton, Leicester, Limerick, Norwell, Raynham, Ridebury, Rumney, Saco, Scantic, Scarboro, Stissing, Swanton, Walpole, Wareham, Whitman series.

Group 8

Poorly drained organic soils of the wetlands. These include organic soils of the cranberry bogs, freshwater marsh, muck, peat, sandy muck, and tidal marsh. Because the water table is at, near or covering the soil surface these soils were not considered for prolonged wastewater application. However short term wastewater application could have possibilities, in renovating wastewater to acceptable levels.

The following criteria were used to classify the soils into the above group.

LIMITATIONS FOR WASTE WATER DISPOSAL

Soil Properties	Slight	Moderate	Severe
1. Depth	5 ft. or more	3 to 5 ft.	less than 3 ft.
2. Drainage	Well drained	Moderately to well drained	Poor and very poor
3. Texture	Silo, lo, fsl, lfs *	lo sd, sd *	Gravel and Cobbles
4. Fragipan	None	Well drained with fragipan	All other drainage
5. Slope	0 to 8%	8 to 15%	15%+
6. Stoniness	None	Very Stony	Extremely Stony
7. Flood Hazard	None	Occasional	Frequent

* silo-- Silty Loam; lfs - Loamy Fine Sand
lo-- Loam; lo sd - Loamy Sand
fsl - Fine Sandy Loam; sd - Sand

SECTION III - A

FINDINGS - MERRIMACK RIVER BASIN

THE MASSACHUSETTS PORTION OF THE MERRIMACK RIVER BASIN

1. LOCATION, TOPOGRAPHY AND DRAINAGE

The Merrimack River Basin within Massachusetts occupies some 1200 square miles between the New Hampshire State line and the abutting river basins to the east, west and south. Those bounding the area include the Connecticut River Basin on the west, the Blackstone on the south, and the Charles, Mystic, and Ipswich River Basins to the east.

Eastern portions of the basin lie within the Seaboard Lowland section of the New England physiographic province. The topography in this sector is characterized by low rounded hills and broad poorly drained lowlands. Proceeding west the relief gradually changes to that typical of the Upland Sections of the province. Here the topographic forms are accentuated; higher, steeper hills are seen and the rivers appear incised into narrower valleys.

Drainage in the report area, by definition, ultimately reaches the Merrimack River. Principal tributaries to the Merrimack in Massachusetts are the Nashua and Concord Rivers. They in turn are supplied by a number of smaller streams, the Assabet and Sudbury Rivers being the most extensive of these. Small portions included along the "edges" of the report area are drained by rivers and systems other than the Merrimack. These areas are described in individual RPA reports (Section II, parts 1 - 5).

2. BEDROCK GEOLOGY

Many bedrock geology studies on various portions of the Basin area have been utilized to complete this report and its accompanying maps. Some of these studies provided detailed information in a particular area, such as Hansen's (1956) Geology of the Hudson and Maynard Quadrangle. Others provided maps of regional geology, describing and correlating bedrock units in other parts of New England with similar sequences in the Basin (e.g. Billings, The Geology of New Hampshire, Part II, 1956). A few specialized investigations supplied maps of structure or lithologies on a regional basis such as Skehan's (1967) map showing Tectonic Features in New England or the USGS (1967) Engineering Geology of the Northeast Corridor. But only one, Emerson's Bedrock Geology of Massachusetts and Rhode Island, yielded a comprehensive map and discussion of bedrock units, as well as their structure and age, in the entire area. As a result this report essentially reflects Emerson's work; any differences are due to updates and modifications provided through more recent studies. An attempt will be made here to review those differences as they apply to the information presented.

Lithology

The lithologic descriptions for each bedrock formation were obtained primarily from those given by its author. Detailed rock unit descriptions are found in Section III. B. A summary of the various units and their descriptions is provided on Table 2.

Another source of lithologic information is the U. S. Geological Survey's Northeast Corridor Study (1967). This is essentially an engineering study in which the various geologic materials have been mapped as "units having similar engineering characteristics". Hydrologic conditions for many of the rock types in the report area are described. These include water depths, well depths, yields, and other hydrologic features.

Stratigraphy

The ages, sequences and names given to various bedrock units have been summarized on Table 1. At a glance it may be seen that the geologists whose information is presented differ widely as to the stratigraphic relationships among the various units. Although the more recent and presumably most accurate data is incomplete, we have attempted to "update" Emerson's work with the following changes and/or additions.

The Rice Formation, Kendall Volcanics, and Cherry Brook Formation, all of reported pre-Devonian age, have been added to the bedrock map for the Merrimack-Metropolitan RPA Area (B5). These rock units were identified and mapped by A. E. Nelson (1973), in the Natick Quadrangle.

The mapped limits of the Westboro Quartzite and Marlboro Quartzite have been altered to include areas mapped by Hansen (1956) and Nelson (1973) in the Hudson, Maynard and Natick Quadrangles (see pages 68-69, Figure B5).

Gneisses and schists of undetermined age as described by Emerson may be separated into three groups. A large mass located in portions of four RPA Areas has been mapped as the Nashoba Formation (Hansen, 1956). These rocks were described by Emerson (1917, p. 80-86) as the "Bolton" gneiss. Their limits were mapped in part from LaForge (1932, p. 3), Billings (1956, p. 100), Hansen (1956, plate 1) and Jahns, Willard, White, et al (1959). Two remaining groups of gneisses and schists of undetermined age have been left unassigned. The first is located in the Merrimack Valley, Northern Middlesex and Merrimack-Montachusett RPA Areas, and adjacent regions of New Hampshire.

Billings (1956, p. 44 & 100) refers rocks in this area to the Merrimack group of Silurian (?) age. Skehan (1967, Figure 2) maps and describes a portion of this unit as the Chelmsford Granite, possibly a granitized form of the Merrimack Quartzite (also mapped by Jahns, Willard, White, et al, 1959). The second group occurs in the Merrimack-Metropolitan RPA Area near the eastern limits of the Basin. LaForge (1932, p. 16-17) has assigned some of the rocks in this region to his Waltham Gneiss of pre-Cambrian (?) age, but Bell (1948) disagrees and has referred these outcrops to other groups (Westboro Formation, Marlboro Formation, Woburn Formation, and others).

The Gospel Hill Gneiss and Acton Granite units named by Hansen (1956) have been delineated and added to portions of the Merrimack-Metropolitan Area bedrock map. So has Hansen's Salem (?) Gabbro-Diorite area in Sudbury and Concord; and Nelson's (1973) "Gabbro" in the Natick Quadrangle.

Structure

The broad northeasterly structural trends present throughout the study area will be described later in the report, as will opinions by many of the geologists whose work on the structural/age relations of the region are well known (Emerson, 1917; LaForge, 1932; Billings, 1956 and others).

Specific tectonic features, however, are discussed very little. Emerson's map, for instance, displays few faults of either major or minor proportions; far fewer than would be expected in an area once so active. Within the past 10 to 15 years a considerable amount of new information has been published about faults and their locations in New England. Although it would be beyond the scope of this report to detail these findings, at least two significant sources of tectonic information for the study area should be pointed out. One is a map presented in the Corridor Study (1967, Figure 1-514-A). This map displays faults on a regional basis and presents structure section diagrams. Another is the work of Skehan (1967, p. 237-244) and others, who in describing the geology of the Wachusett-Marlborough Tunnel have located a fault zone of major proportions in east-central Massachusetts. The description cited below is accompanied by a small scale map showing the location of this fault zone and its relationship to other significant tectonic features in southern New England.

> " The tunnel sequence lies within a zone which has been highly faulted and intensely deformed. The most prominent fault zone mapped by the writer in this tunnel is in Clinton Township. The strike of the fault planes bounding this zone is N40E, dipping at 35° to the northwest. This Clinton fault

zone, projected from the tunnel to the surface, was later traced on the surface northeasterly to the vicinity of Lowell and into southeastern New Hampshire (Castle, 1965). This great fault zone, seen by the author in the subsurface and identified as an important dislocation zone, is traceable in reconnaissance fashion by extrapolation from Emerson's 1917 geologic map. In part at least, the boundary of "gneisses and schists of undetermined age" coincides with the Clinton fault zone and its branches. On this basis, lateral and vertical motions must therefore be of the order of miles and actual displacement must be of the order of at least tens of miles.

The marked angular relationships of the boundary between "gneisses and schists of undetermined age" with rock units north and west of this line mark the location of the continuation of the Clinton fault zone beyond the northeast side of the tunnel. Southwest of the tunnel the Clinton thrust may strike about N20°E. Either a branch of this important fault zone or the main fault itself may be traced in a southerly direction to near the intersection of the Massachusetts, Rhode Island, and Connecticut boundaries where its probable continuation, the Honey Hill fault, has been traced."

Goldsmith and Page (1973, p. 13) present additional information about the same area.

"<u>Tectonic thinning in the Nashoba Formation</u>

In the Westford, Billerica, and Concord quadrangles, complexly interstratified metamorphosed volcanoclastic and epiclastic rocks of the Nashoba Formation have been subdivided into 16 litho-stratigraphic map units with an aggregate thickness of 44,000 feet. According to D. C. Alvord, many of the map patterns of these rocks, formerly interpreted either as the result of folding or as facies changes, are the result of juxtapositioning and/or removal of portions of the rocks by displacements within systems of subparallel east-northeast-trending high-angle reverse faults and related transverse faults. Mapping southwesterly along one such fault shows the removal of 5,000 feet of strata from its upper (northwest) plate in a distance of seven miles. Three major subparallel zones of such faulting, together with some less extensive faults have, in a distance of 25 miles, progressively sliced out Nashoba rock, narrowing its outcrop belt gradually southwesterly from a 12-mile breadth in the Westford-Concord area to a 3-1/2-mile breadth in the vicinity of the Wachusetts-Marlboro aqueduct where J. W. Skehan and A. Adel Abu-Moustafa found the stratigraphic thickness of the Nashoba to be 10,942 feet (written commun., 1972). Thus, it is inferred that at least 75 percent or some 33,000 feet of section has been removed from the Nashoba Formation by faulting in the Wachusetts-Marlboro area."

In all probability additional undiscovered major faults exist within the Basin. Their discovery and interpretation will be of great significance in unraveling the age, structural and stratigraphic relations among the bedrock units in the area.

3. SURFICIAL GEOLOGY

Nearly all of the bedrock units described from the Merrimack Basin area are of Paleozoic age or older. Except for a few diabase dikes of reported Triassic age, rocks of Mesozoic and Cenozoic age are unrepresented in the report area. It has been proposed that the unconsolidated surficial material of glacial and recent age lie on a deeply-eroded rock surface of very ancient age. This surface has been described as a peneplane by Alden (1924) and others, into which pre-glacial streams became entrenched during periods of uplift and renewed erosion.

Downcutting by these streams was interrupted by passage of one or more glacial ice sheets during the Pleistocene epoch. Much of the mantling cover of soil and weathered rock was removed by the ice sheets, and the underlying land masses subjected to glacial abrasion and scouring.

Upon and over this modified surface one or more layers of debris were deposited by the glacial ice. Later, as the ice melted, water-borne drift accumulated between, among, and over residual ice blocks, and was washed out into the basins of temporary glacial lakes. Many of the ancient pre-glacial valleys were blocked or filled with sediment and the streams, having been diverted from their original channels, developed new courses. During this deglaciation stage open bodies of water, the larger glacial lakes and the Atlantic Ocean, received finer grained sediments. These accumulated to considerable depths particularly in the latter instance.

After the glacial ice had receded the land mass began to rebound exposing some of the newly deposited materials to erosion. During and following this period the sea first retreated, then re-advanced. Along its shores glacial sands were whipped into dunes by the wind, open waters filled with sediments and on these a marsh system evolved.

Landward, the large glacial lakes had drained through a successive series of lower elevation outlets. Rivers and streams became established in new courses and channels, re-established flood plains, and in some cases went immediately into mature stage development complete with meanders, oxbow lakes, and natural levees.

Poorly drained upland areas and old lake bottoms, along with some of the deeper kettle holes in outwash areas became partially filled with organic detritus.

Thus the various unconsolidated surficial materials accumulated; all are of Pleistocene or recent age. Table 3 reduces these materials to eight groups, each having specific physical characteristics. The paragraphs below summarize the nature of the materials and the extent of their occurrence within the Basin area.

Glacial Tills

Considering the surface area exposed in the Merrimack Basin, glacial till is the most common geologic material. The deposit, however, is usually thin and probably averages less than 20 feet thick. In western portions of the Basin till is more prevalent than in eastern sectors, but it is generally a rather limited mantle of ground moraine over shallow bedrock in these areas. In the central, southern, and eastern parts of the report area drumlin hills become common, and the thickness of the deposit may locally reach 150 feet or more.

At least two distinct types of glacial till are present in the report area; one is the so-called "older till", the other the "younger till". Hansen (1956, p. 61) describes each and summarizes the opinion regarding their origins.

> ". . The younger till is light gray to light bluish gray where freshly exposed. It has a yellowish- or brownish-weathered zone that commonly extends to a depth of 1 to 3 feet. Below this the till is fresh and unaltered. Characteristically it is loose, incoherent, and relatively pervious, and slacks quickly on drying. Its texture is relatively coarse, and it contains many boulders.
>
> The so-called older till is light brown to yellowish brown and dusky yellow. This coloration apparently is a result of deep oxidation. The weathered zone of the older till, as here observed in the upper parts of exposures, is essentially similar to that of the younger till. The older till is somewhat finer and certainly less bouldery than the younger till. Also it possesses a prominent cleavage or fissility that lies essentially parallel to the

ground surface. It is compact, tough, coherent, and relatively impervious. On drying it indurates to a hard, almost concretelike mass. It is more difficult to excavate than the younger till, therefore, and has earned the local name of hardpan, but it is easily worked with power shovels.

The younger till probably has a broader surface distribution than the older till but probably is less in total volume. In many areas, the older till is exposed at the surface, and in such places the surface tends to be smoother and more even than younger till areas and therefore exhibits subdued relief features.

Two explanations have been offered to account for the dissimilarities of the two tills. One view holds that a considerable time interval elapsed between their deposition, that the older till was deposited by an ice sheet that advanced and withdrew from the area before a later ice sheet (or a readvance) deposited the younger till. The other view holds that both tills are accumulations from a single ice sheet, that one till is a basal accumulation and the other is an englacial or superglacial accumulation. Both views have many adherents, and until unequivocal evidence is discovered, such as a buried soil or an interglacial deposit, agreement on the problem probably will not be reached."

In terms of the maps presented with this report, the debate is superfluous; both types of till are mapped as one unit (see maps S1-S6).

Glacial-fluvial - Glacio-lacustrine

Outwash Deposits - Ice Contact Deposits

Coarse grained stratified drift deposits are mapped and discussed together for each RPA Area. Although the outwash and ice contact deposits may differ significantly in their origins and/or final topographic forms, they are similar in physical characteristics. Most often these deposits consist of sands or sand and gravel with minor amounts of silt and/or clay (less than 10%). They are usually stratified and somewhat to well sorted.

Large quantities of these materials are found among the deposits which accumulated in temporary glacial lakes; those described elsewhere as glacial lakes Nashua, Assabet, Charles, Sudbury, and Concord being the largest identified thus far in the basin.

Other types of stratified drift, although not as extensive as glacial lake deposits, are significant in certain areas. One is the large complex of kames and outwash in northeastern Essex County described by Katz and Keith (1917) and Chute and Nichols (1941).

In terms of their surface distribution and total volume, the coarse-grained outwash and ice contact deposits are probably second only to the glacial tills.

Glacio-lacustrine

Glacial Lake Bottom Deposits

The materials mapped and described as lake bottom deposits are limited to those finer grained materials that originally accumulated on the floors of temporary glacial lakes. They are most commonly seen today where spread broadly over valley floors and in level plain-like areas such as near Hanscom Field in Bedford. This deposit represents the ancient floor of glacial Lake Concord.

The materials referred to lake bottom deposits are primarily silts and/or sandy silts. Varved clays are reported from the Nashua and Sudbury Valleys among the glacial Lake Concord deposits, and to lesser extents elsewhere in the Basin.

Glacio-marine

Marine Clays

Blue-gray silty clays are found along coastal sections of the Basin. They are most often described as late-glacial and post-glacial age marine deposits. The occurrence of this clay well above modern sea level elevations indicates landward submergence during the time of its deposition. As described by Hartwell (1970, p. 155), the relative sea-land levels in this area have changed several times.

> ". . the blue clay was deposited during later Pleistocene time in an estuarine area at or near sea level. By 10,500 B.P., the ice had retreated and the land was rebounding more rapidly than sea level was rising. About 7500 B.P., the land reached its maximum uplift while sea level reached maximum regression. By 6300 B.P., the land began to subside and the sea started transgressing over the glacio-marine blue clay...At about 3000 years B.P., a marked decrease in the rate of sea-level rise occurred along much

of the New England coast (McIntire and Morgan, 1963; Bloom and Suiver, 1963). Since then sea level appears to have reached stillstand while crustal downwarping in the Plum Island area continues at a rate of about 9.1 cm per century."

Glacio-Marine-Recent

Marine Sands-Dune Sands-Beach Sands

Sands and silty sands associated with the glacio-marine clays described above are mapped together with recent dune sands and beach sands. For the most part the recent beach sands along the Atlantic coast of Plum Island have been derived from glacial materials transported as shore drift. The large dunes on the island have been developed by on-shore winds blowing across these sandy beaches.

Ancient dunes now anchored by vegetation and no longer active may be seen throughout the Basin area. Many of these deposits formed in late glacial times along terraces, lake bottoms, and "sand plains" where the barren glacial outwash sands were swept into dunes by strong winds.

Recent

Marine Organic Deposits

Recent age marine organic silts are found in coastal lowland regions, particularly in the large salt marsh behind Plum Island. The formation of this deposit is related to fluctuations in the sea level as were cited above. Hartwell (1970, p. 136-142, p. 163) describes the deposit and discusses its formation:

> " The Holocene stratigraphy of the Merrimack marshes is similar to that observed by McCormick (1968) in the Parker River marshes. Almost everywhere the marsh is topped by a zone of living high salt marsh. This layer is generally underlain by a thick deposit of high salt-marsh peat which grades into a sandy to muddy low salt-marsh peat. Many of the cores bottomed in a gray, silty to sandy intertidal facies believed to be analoguous to the clam-flat and tidal-channel environments in the present estuary. (Several cores) had layers of dark-brown to black peat believed to be deposited by fresh- to brackish-water plants. This peat is analogous to that found under the Parker River marshes (McCormick, 1968) and in many of the New England

marshes. All workers agree that this peat represents an accumulation of fresh- to brackish-water sedge-type plants, deposited in the zone of transition from salt marsh to normal highland vegetation or at very near mean high-water level."

" An offshore barrier island was present in the vicinity of Plum Island as early as 6000 B.P. Fine-grained sediment accumulated behind the island in an open bay environment with a fringing fresh- to brackish- water marsh. With rising sea level, these sand-flat and mud-flat sediments transgressed landward over a black peat layer deposited by fresh- to brackish-water plants. At about 3000 B.P. the rate of sea-level rise slowed down enough to allow the fringing marsh to accrete seaward over the open bay sediments. Once the marshes grew above the intertidal zone, high salt marsh plants were able to establish themselves. As a result of this regression of marsh deposits, the original open bay environment was transformed into the present marsh system with tidal channels and islands."

Recent

Fresh Water Organic Deposits

Fresh water swamp accumulations throughout the area consist of peat and other decomposed organic matter interbedded in places with sands and silts. They are most extensive in valleys and lowlands where they overlie lake bottom deposits, alluvium, or outwash. Elsewhere they occur locally in kettles, or in poorly drained upland rock basins and depressions in the ground moraine. The swamp deposits are generally thin in upland locations, but in several lowland areas are known to exceed fifty feet.

Recent

River Terrace and Alluvium Deposits

Much of the material picked up, transported, and deposited by streams has been derived from glacial deposits. Some of this material was deposited in post-glacial times along river courses that are now abandoned or partially abandoned. River terraces and other features that represent these older stream courses are seen throughout the area.

Present day rivers and streams deposit alluvial materials in their channels and along flood plains. Such materials include gravel, sand, silt, and clay size particles. The coarser fractions represent bedloads of the streams deposited by lateral migration. Finger materials, silt and clay, are deposited by overbank flooding of the streams and rivers. The modern flood plains of the Merrimack and Nashua Rivers are the most extensive in the basin area.

4. GROUND WATER GEOLOGY

Ground water favorability for the Merrimack River Basin, while not mapped in detail from extensive field investigations or obtained from other maps based on detailed field work, is possible to outline on the basis of known surficial geology and observed ground water relationships. A close correlation between two characteristic ground water situations and the geology of the basin above bedrock permits mapping of the regional ground water patterns shown in Figure W6. As will be noted for those individual RPA Areas, the ground water patterns mapped here must be considered as a reconnaissance estimate everywhere except in the Assabet River drainage basin (see Map I3). However, the relationships are close enough to expect that the main ground water characteristics for the Merrimack Basin as a whole are displayed in the mapping.

Mapping units in W6 parallel the units shown for the RPA Areas and are essentially a reproduction of U. S. Geological Survey ground water favorability map units. In abbreviated form, the map units and relationships include:

A. Unfavorable for the development of ground water supplies (in terms of surficial geologic units; this ground water unit includes essentially all areas mapped as glacial till as well as some areas of other deposits which do not have characteristics deemed favorable for either transmission or supply of underground water). The unfavorable areas are shown in Figure W6 as having no pattern other than surficial geology pattern.

B. Favorable for development of moderate ground water supplies. These areas are shown as a pattern of closely-spaced stippling over the surficial geologic map units. (Favorability at this level is essentially the equivalent pattern for areas of stratified glacial drift, excepting where there is no surface evidence of constant supply or where thick saturated deposits might be inferred from other mapping).

C. Favorable for development of moderate to large volumes of ground water. These areas, which are shown in Figure W6 by the large dot stippling, are considered the least complete ground water unit of the maps. (Areas of high favorability are based either on known localities of high groundwater production or where the location of deep buried river channels with permeable deposits are known).

Details of the potential volume of water available from these units is discussed in paragraph D. 2, and the information regarding map sources is given in paragraph D. 1. (section II, page V and VI).

While the patterns of ground water favorability appear at first to be very irregular, some regularity in the overall trends may be noted:

1. In the northeastern and western parts of the basin, the thickness and presence of stratified deposits is less than that elsewhere, and the net area of deposits showing anything other than low favorability is correspondingly less.

2. Nearly all areas of moderate to high favorability parallel a northeast-southwest grain (as does the surficial deposit trend) except in the current river valleys which may show a northwest to southeast trend.

3. Virtually <u>all</u> highly favorable areas are at the inferred locations of buried river channels; these could possibly be significantly expanded in area and extent if accurate and detailed locations of the channels could be delineated.

Known positions of several buried channels have been drilled and bedrock elevations in the channels are often found to be at or below the present sea level--these elevations must be present throughout much of the basin for the water in the pre-glacial rivers to flow, and many potential sources of highly productive deposits should also be present.

Finally, note should be taken of the fact that groundwater favorability as shown on Figure W6 does not imply anything about groundwater quality. In those deposits supplied by the surficial streams or rivers of the basin, the quality of the water might vary considerably with removal of the present supply. This situation should be noted especially in the lower channel of the Merrimack River, which is tidal as far upstream as the City of Lowell, and in the deposits very near the courses of the upper reaches of the Merrimack and along the Nashua River.

5. <u>SEISMICITY AND SEISMIC CONSIDERATIONS</u>

Occurrence of earthquakes in the Merrimack Basin proper and in surrounding regions which might influence the study area must be rated "low" to "intermediate" in comparison to the general seismic character of the United States. However, the northeastern part of the basin (near Newburyport) includes one of the most seismically active areas along the Eastern Seaboard, and ground conditions which exist in the Basin indicate that evaluation of the seismicity in this study is a necessary and valid consideration.

The location of earthquakes which have occurred in New England relative to the Merrimack Basin are shown in Figure 1. The epicentral locations are plotted after data given Brooks, (1959) and Chung and Ingersoll, (1973). Historical seismicity records for the region extend to 1534, but accurate locations and acceptable magnitudes for realistic seismic evaluations do not exist much prior to 1940. In the ensuing 30 years plus, the constancy of operation of seismic recording stations to make location and magnitude estimates of earthquakes has varied considerably, and the data plotted can be considered only as a "figure-of-merit" for the actual seismic activity in the New England region.

Devane and Holt (1967) note that the rate of occurrence of earthquakes in California is about 30 times that of the New England region over a very broad range of source magnitudes. In terms of potential structural damage, however, the intensity of ground motions at any particular site are critical from the engineering standpoint and the number of events/magnitude/intensity relationships are not well known. It is known that ground conditions above bedrock are critical to the observed intensity of ground motion at a site (Barosh, 1969), that distance from the source has both an amplitude and duration effect upon intensity (Jackson, 1967; Esteva and Rosenbluth, 1964; Kanai, 1961; and others), and that intensity-related structural damage is closely related to geological ground condition over very wide regions (Evernden, et al, 1973). Difficulties regarding the evaluation of these parameters are discussed by Whitman (1970).

Those general ground conditions of importance to seismic considerations in the Merrimack River Basin are well-expressed in a comparison of the bedrock-surficial-ground water geological maps given in Section II. The following types of soil substructures which should be evaluated in detail at a specific site for seismic intensity influence include:

1. Those areas of swamp and swamp deposits which are underlain by a saturated column of glacial or glacio-fluviatile origin. Swampy areas directly overlying bedrock are not particularly more susceptible to an intensity increase above that of the bedrock itself.

2. Permeable glacial and alluvial deposits which are saturated to within about 5 meters (15 ft.) of the ground surface. Greater intensities may be anticipated with increasing thickness of the saturated column (including buried river channels). Well-drained soils with the ground water table below 5 meters depth are usually stable.

3. The presence of plastic clays in the soil substructures, or clays which are potentially plastic under uncommon ground accelerations.

4. Any soil structure above or near an active fault.

Examples of the first three soil conditions are present in the Basin proper, the fourth has not as yet been identified.

On the basis of rather sketchy historical observations, potentially damaging earthquakes with local seismic intensities of as great as VIII on the Modified Mercalli Scale (damage great in poorly designed structures) may be experienced in the northeastern part of the Merrimack Basin. Intensities which result in slight damage and some moderate personal discomfort are generally indicated for the rest of the Basin region.

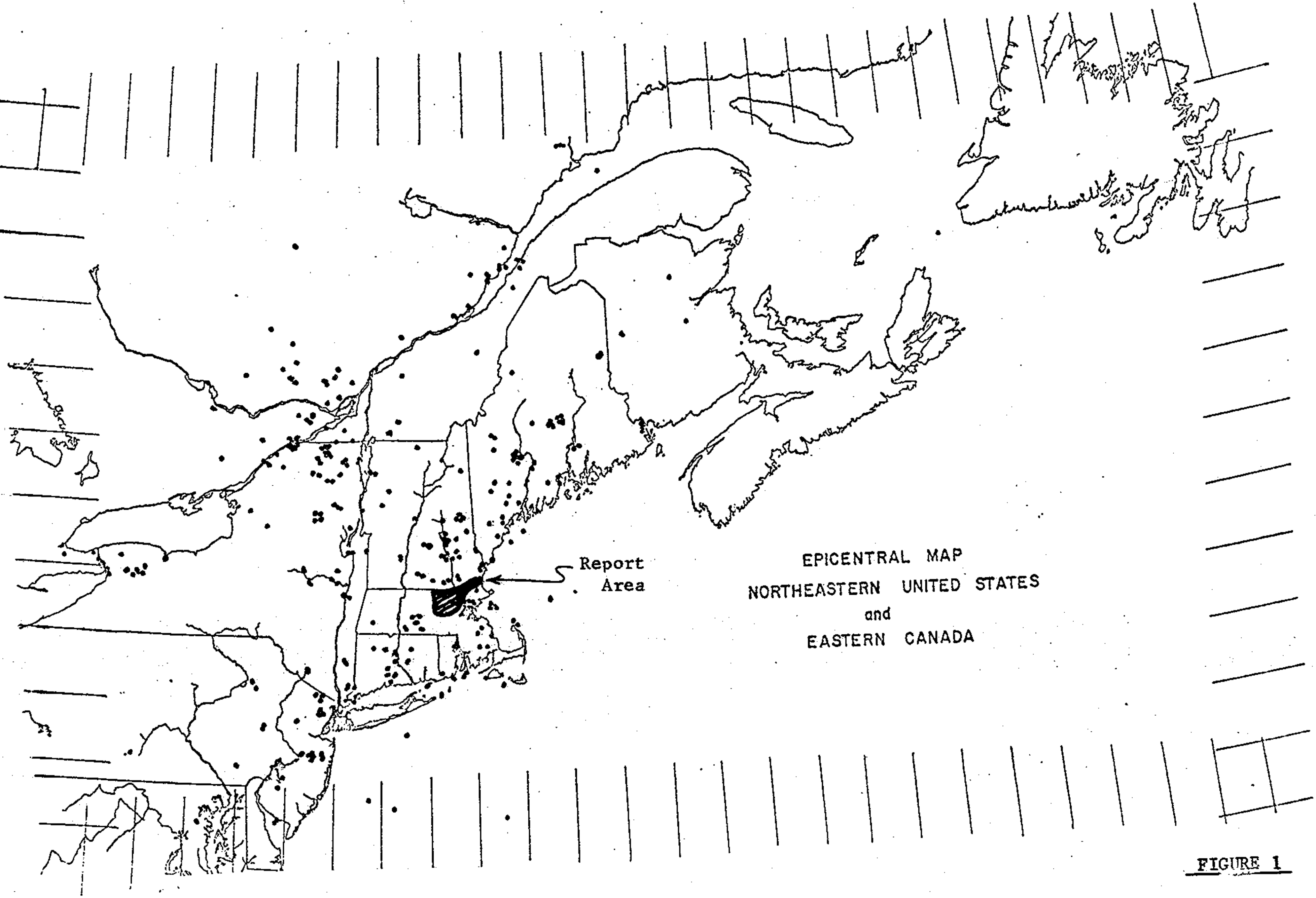

Report Area
EPICENTRAL MAP
NORTHEASTERN UNITED STATES
and
EASTERN CANADA

FIGURE 1

A SUMMARY OF THE AVAILABLE INFORMATION
SHOWING THE DISTRIBUTION OF BEDROCK UNITS
IN THE MERRIMACK RIVER BASIN (MASSACHUSETTS PORTION)

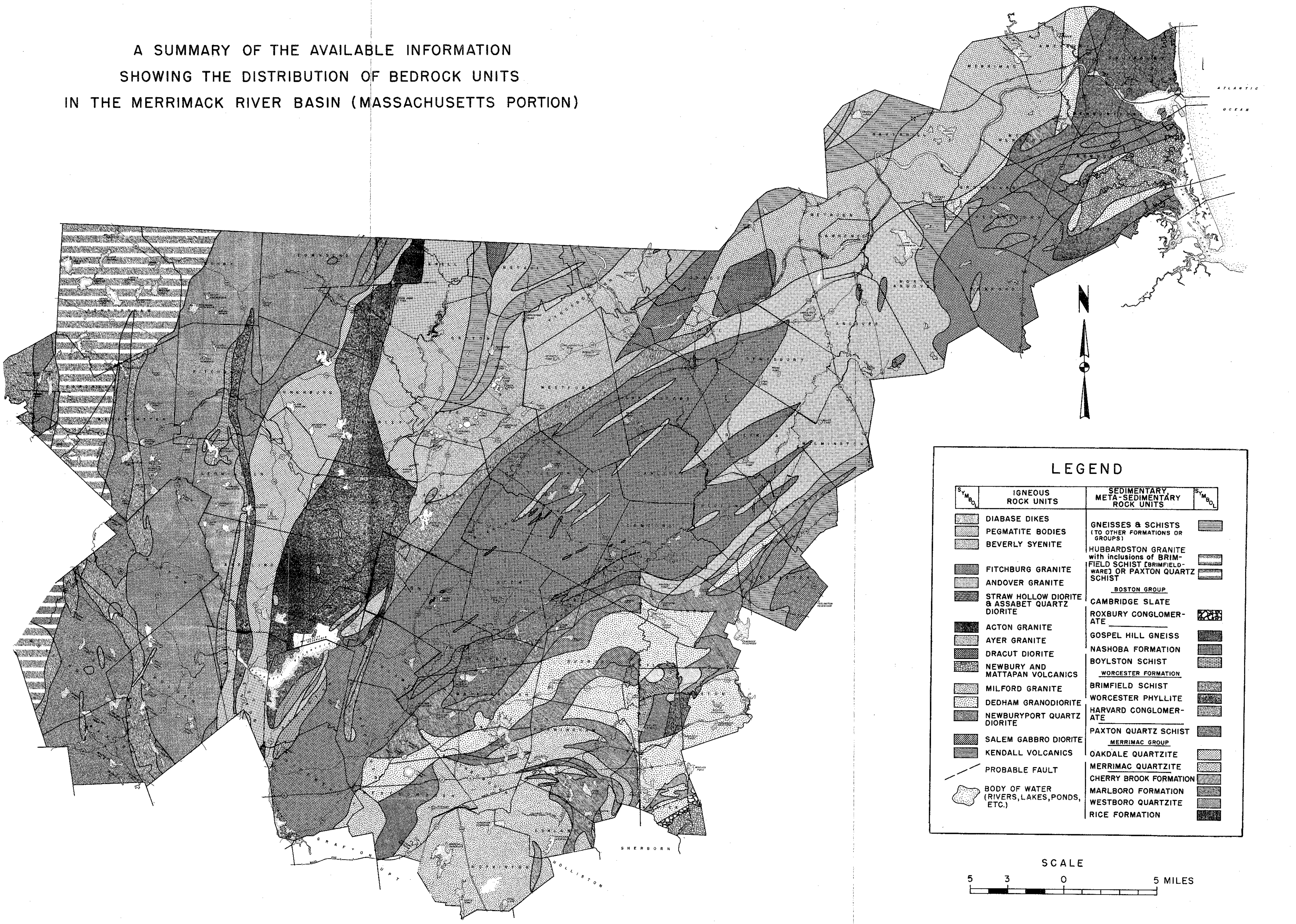


FIGURE B6

PREPARED FOR CORPS OF ENGINEERS BY
ANDERSON-NICHOLS CO. INC. AND
GOLDBERG-ZOINO & ASSOC., INC.

PRELIMINARY ESTIMATE OF GROUND WATER FAVORABILITY IN THE MERRIMACK RIVER BASIN (MASSACHUSETTS PORTION)

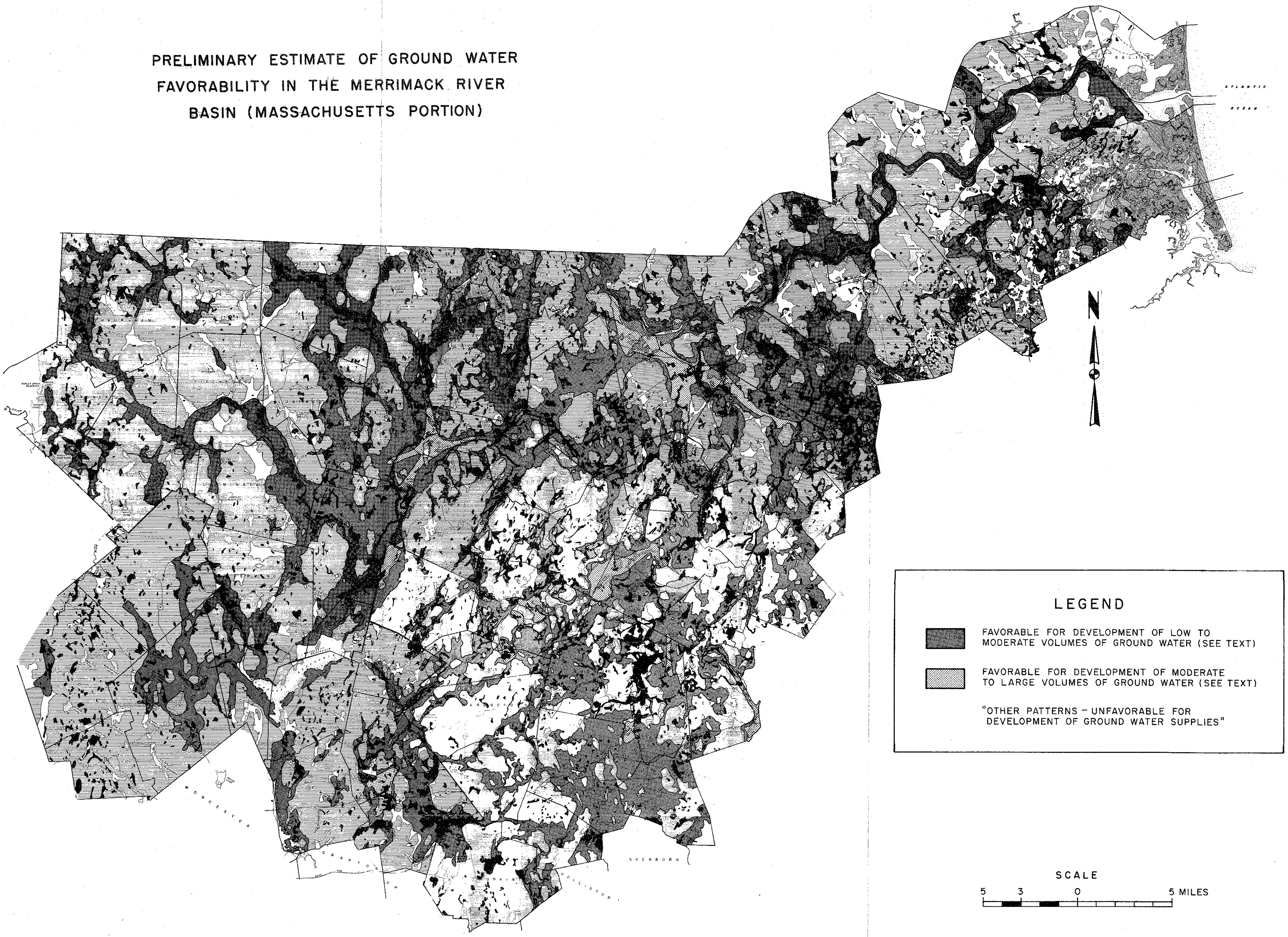


FIGURE W6

PREPARED FOR CORPS OF ENGINEERS BY
ANDERSON-NICHOLS CO. INC. AND
GOLDBERG-ZOINO & ASSOC., INC.

SECTION III - B

FINDINGS - RPA AREAS

MERRIMACK RIVER BASIN

1. MERRIMACK VALLEY PLANNING COMMISSION

A. LOCATION, TOPOGRAPHY AND DRAINAGE

The Merrimack Valley RPA Area is located within Essex County in the extreme northeastern portion of Massachusetts. It is bounded to the east by the Atlantic Ocean, to the north by the New Hampshire State line, to the west by the Middlesex County line and to the south by the towns of Ipswich, Topsfield and Middleton.

The report area is situated in the Seaboard Lowland sector of the New England physiographic province. Within this sector, however, the area may be broadly divided into two regions which differ significantly in their topographic form. The first is a coastal plain region, a strip 5 to 10 miles wide along the Atlantic Ocean. This is an area of little relief occupied primarily by marine marshes and tidal flats a few feet above sea level. The second region occurs to the west and contrasts with the eastern portion in that the ground surface is more irregular and undulating. The topography here is controlled by bedrock prominences and/or hills of glacial debris. These uplands fringe and separate the valleys of the Parker, Ipswich, Shawsheen and Merrimack Rivers.

The Merrimack River drains much of the area and flows generally in a west to east direction. It is joined by the Shawsheen near Lawrence and further east by the Pow Wow River and other minor tributaries. Parts of the Parker, Rowley and Ipswich River Basins are included in this RPA Area. They, however, do not enter the Merrimack but arrive at the Atlantic Ocean at Plum Island Sound.

B. BEDROCK GEOLOGY

Bedrock formations of several types outcrop in the Merrimack Valley RPA Area. These occurrences are most numerous along ridges and knobs of the western upland portions of the region, although the bedrock in the Merrimack River Estuary is thought to be relatively shallow (Hartwell, 1970, p. 4).

The bedrock geology of the region has been described by Sears (1905), Emerson (1917), Clapp (1921), and Chute and Nichols (1941). Studies on adjoining areas by LaForge (1932), Toumlin (1964), and Jahns, Willard, White and Currier (unpublished) have been utilized in preparing this report, as has Billings' work in New Hampshire (1956).

As described by Clapp, the rock units of this area are chiefly of Paleozoic age, although some were thought to be of pre-Cambrian age. Later workers refer most of the rocks in the district to Paleozoic formations and units, with lesser amounts of Triassic age dikes.

The most recent interpretations of the bedrock in northeastern Massachusetts refer the igneous rocks in the area to three plutonic series. The oldest of these is the Dedham Granodiorite and other related diorites, granodiorites and granites. The stated age of these units ranges from late pre-Cambrian to early Paleozoic. A younger group includes diorites, quartz-diorites and granites, one of which is the Andover granite. The youngest group has been tentatively placed in the Middle Paleozoic. These rocks are the Beverly Syenite, parts of the Salem Gabbro-Diorite and others collectively known as the Cape Ann Plutonic Series. Volcanics in the area (Newbury Formation) have been described as of Middle Paleozoic age (Toulmin, 1964).

Metamorphic, in particular meta-sedimentary and meta-volcanic rocks, occur among the plutonic series. These units include the Marlboro Formation, the Merrimack Quartzite and Emerson's mapped units of Gneisses and Schists of undetermined age. The latter group has in part been correlated by Billings with the Merrimack Group (1956) and has been assigned a Silurian age. Recent workers place the Marlboro Formation in the pre-Silurian age (Goldsmith & Page , 1973).

All of the metamorphic formations have been folded and faulted. They are, in many places intruded by plutonic rocks of one or more of the series mentioned above. The strike of these rocks is generally northeast, parallel to the trend of a large complexly faulted anticlinal structure.

It needs to be restated here that understandings of the age/structural relations of bedrock units in this area are incomplete. **Further work is needed and is in** progress by various U.S. Geological Survey personnel. Until such time as their work is made available, tentative examinations and explanations will have to be made using older publications. Consequently the bedrock map of the Merrimack Valley RPA, as well as the following descriptions of rock formations and their areas of outcrop, are based primarily on work by Emerson, Clapp, and LaForge in the early 1900's.

METAMORPHIC ROCKS

Marlboro Formation

Rocks assigned to the Marlboro Formation in this area, as described by Emerson (1917, p. 28),"..... occur for the most part in comparatively small isolated lenses and ovals surrounded by and included in the Paleozoic igneous rocks." His description of the Marlboro rocks in northeastern Massachusetts follows:

" The Algonkian (?) rocks consist chiefly of a number of sorts of schist, but include also many beds of quartzite, a number of small bodies of limestone, and a few small lenses of conglomerate. Many of the schists are of sedimentary origin and represent former argilaceous or calcareous beds; others are volcanic and represent flows and contemporaneous intrusive sheets of both rhyolitic and basaltic lavas. Some of the schists are probably metamorphosed tuffs. All the rocks are greatly altered and most of them are completely crystallized and highly schistose. The schistosity is nearly everywhere parallel to the original bedding, which in most places is still easily distinguishable. The beds are, as a rule, steeply tilted and although there are many exceptions, there is a strikingly prevalent tendency throughout northeastern Massachusetts, even in the smaller and more isolated areas of these rocks, toward a northeast-southwest strike and a high northwesterly dip."

Merrimack Group - Merrimack Quartzite

According to Clapp (1921, p. 19) the Merrimack Quartzite underlies unconsolidated glacial materials over a wide belt extending along the Merrimack River from the western boundary of Essex County, across nearly its entire width to near Salisbury, where it crosses into New Hampshire. Clapp's description follows:

"...In the northeastern part of the belt all of the rocks have a pronounced schistose texture and are in greater part fine-grained phyllites and mica schists. Some are shaly in appearance and many are carbonaceous or graphitic. In places they are massive.

.... The strike of the formation is northeast ranging ordinarily from N 30°E to N 70°E. The dips are nearly everywhere to the northwest and are usually steep, 50° or more.

Gneisses and Schists of Undetermined Age

Emerson (1917, p. 80) maps and describes a series of rock units crossing northeastern Massachusetts under the category of Gneisses and Schists of Undetermined Age. Two such areas are included in this report area. One extends from the Merrimack River near North Chelmsford northeastward past Haverhill where it crosses into New Hampshire near Plaistow. Another mapped area lies between North Andover and Boxford. He has described the rocks of these two areas as being of sedimentary origin, and;

> "...The main type is a rusty quartz-biotite schist or gneiss, with which are interbedded in many places layers of hornblende schist and of actinolite quartzite. No limestones or limestone derivatives are known in these areas. The original formation must have been sandstone and graywacke, and perhaps a little shale. The sedimentary beds now alternate with countless intrusive sheets, from a few inches to many feet thick, of gneissoid granite and with a few such sheets of gneissoid diorite. They are also cut by larger lenses or ovals of granite, most of which are not shown on the map, and all the rocks, both igneous and sedimentary, are cut by veins and dikes of aplite and pegmatite."

Billings (1956, p. 44) correlates the northward extension of the first of these two areas with the Merrimack Group.

IGNEOUS ROCKS

Newburyport Quartz-Diorite

Emerson & Clapp mapped an extensive portion of the Merrimac, Valley RPA as the Newburyport Quartz-diorite. Clapp's (1921, p. 23) description follows:

> "...The Newburyport quartz diorite is a fairly uniform, medium-grained, somewhat gneissic rock consisting essentially of plagioclase (andesine-labradorite), orthoclase, quartz, and hornblende, with accessory biotite, augite, ilmenite, magnetite, apatite, rutile, and titanite. It is greatly altered, the plagioclase having been saussuritized and the hornblende largely altered to chlorite. Calcite is also a common secondary mineral and is in many places abundant."

Salem Gabbro-Diorite

Emerson, Clapp, LaForge and many subsequent authors considered the Newburyport Quartz Diorite, the Salem Gabbro Diorite and the Dedham Granodiorite to be of the same general geologic age. They further explain that although the unit names are used and mapped as separate entities, each of the three types are intricate mixtures of different sorts of rock, and that each includes many small areas of rock types characteristic of the other formations.

The major area which Emerson (1917, p. 179) maps as Salem Gabbro-Diorite extends northeastward to the coast in Newburyport and Ipswich. His description follows:

> " The Salem includes several types of rock. The most characteristic and most widely distributed is a rock containing quartz, labradorite, hornblende, augite, and biotite, to which it is difficult to give a name; it might be called a quartz-augite diorite, a quartz-hornblende gabbro, or an augite-hornblende tonalite, or better still, a quartz gabbro-diorite. It is composed essentially of the minerals named, generally with accessory apatite, magnetite, and ilmenite or titanite, and commonly with more or less secondary chlorite and epidote. It is a medium-grained dark-gray granular rock, ranging to light gray with increase of quartz and feldspar and to greenish and brownish tones where considerably weathered. In a very few places it is porphyritic and contains large phenocrysts of microcline, and grades into the porphyritic granite described above. At some places it is gneissoid or foliated."

Bell, et al. (1973, p. 12) states that part of the rocks which have been called the Salem Gabbro-Diorite are of co-magmatic origins with the Cape Ann Granite, Beverly Syenite and others and are among the youngest igneous rocks in the region.

Dedham Granodiorite

Rocks mapped by Emerson & Clapp as the Dedham Granodiorite occur along a strip parallel to the outcrop area of the Newburyport Quartz Diorite through Amesbury into New Hampshire. Other areas of lesser extent are mapped near Johnson's Pond and near the Parker River.

Clapp's (1921, p. 24) description includes:

> ".... The Dedham granodiorite is a light-greenish, coarse-grained rock, with a somewhat gneissic texture; and in the Newburyport area is porphyritic, with large plagioclase pheoncrysts, 3 to 5 centimeters long. The constituents recognized megascopically are pink feldspar (orthoclase, microcline, and microperthite); white and greenish feldspar (andesine), which is usually in excess over the pink feldspar; abundant quartz; chlorite, epidote; and accessory ilmenite and titanite.

....The granodiorite has been greatly altered, as is shown by its varied and abundant secondary minerals. It has suffered not only from great dynamic metamorphism but also from deep secular weathering."

Newbury Formation

LaForge (in Emerson, 1917, p. 161-164) described volcanic rocks along the Newbury or Parker River Basin as the Newbury Volcanic Complex. Toumlin (1964, p. 14-18) extended the name to Newbury Formation and applied it to meta-volcanic rocks and fine-grained sedimentaries found in the Salem Quadrangle. The rocks as described by LaForge include the following:

" The rocks, with one exception, are wholly volcanic and comprise flows, breccias, and tuffs. The flows comprise rocks of several types, ranging from rhyolite to andesite or basalt. Some of the rhyolites are coarsely porphyritic, some are spherulitic, and some are finely banded. The banded type, an aphanitic or in places semivitreous rock of pink, gray, or green color, predominates and makes up what are probably the thickest flows in the complex. It is also the most resistant rock and stands nearly everywhere in bold ridges.

Associated with the flows of rhyolite, especially with the porphyritic rhyolites, are beds of volcanic conglomerate and coarse rhyolitic tuff. The conglomerates, both pebbles and matrix, consist wholly of rhyolitic material, and in places they grade into the tuffs through beds of medium-grained detritus that might be called rhyolitic.

Several sorts of melaphyre - dacite, adesite, diorite porphyry and probably basalt- are represented among the flows. All the rocks are porphyritic, some strikingly so, and a number are in places amygdaloidal. All are dark colored- gray, olive-brown, and purple - and generally noticeably epidotic, and in grain they range from aphanitic to moderately coarse. Many show flow banding, but others are massive. Among the massive rocks are those of some flows that are probably as thick and nearly as resistant to weathering as those of the great flows of rhyolite.

Associated with the melaphyre flows are volcanic breccias, or mud-flows, and thick beds of tuff. The breccias, or mud-flows, are in places 200 feet or more thick and consist of a poorly sorted mass of fragments, the largest a foot in diameter, and of all shapes- angular, subangular, and rounded- of different types of melaphyre, embedded in a matrix of volcanic mud made up of andesitic or basaltic tuff and fine detritus."

Dracut Diorite

The Dracut Diorite occurs primarily within the adjoining Northern Middlesex RPA Area. Its distribution and characteristics are described in that section of the report.

Andover Granite

According to Emerson (1917, p. 221) the Andover Granite underlies much of the southeastern portion of the Merrimack Valley RPA Area. His description follows:

> " The granite is typically a biotite-muscovite granite of moderately coarse and generally somewhat uneven grain. It is generally, but not everywhere, more or less foliated, and in many places is strongly gneissic. Portions of it are porphyritic, and aplitic and pegmatitic phases abound, both as irregular schlieren in the general mass and as somewhat later dikes and veins with fairly sharp contacts. Its color ranges from nearly white to dark gray, and some of the more gneissic phases are strongly but irregularly banded with white and almost black layers.
>
> The rock is composed essentially of feldspar, quartz, muscovite, and biotite. The feldspars are generally coarse microcline and albite, but a little orthoclase and microperthite are found in some specimens. Muscovite is nearly everywhere present, but considerable masses of the rock contain little or no biotite. Both micas are ordinarily rather uniformly distributed through the rock in moderately small flakes, but in the pegmatitic phases both tend to be segregated and to occur in large plates, an inch or so across. Garnet is common in the rock and is abundant in the pegmatites, in some of which it reaches a considerable development. The granite also displays a greisen phase, consisting almost wholly of quartz and muscovite."

Ayer Granite

Emerson named the Ayer Granite from its type locality near Ayer, Massachusetts. Mapped outcrops in the Merrimack Valley RPA Area are limited to the northwest corner near Ayer Village. Clapp mapped it with the Andover Granite (1921) and Jahns re-classified it as a granodiorite.

Emerson's (1917, p. 224) description includes:

"... The rock is typically a biotite-muscovite granite of moderately coarse grain. In many places it is coarsely porphyritic, containing feldspar phenocrysts 1 to 3 inches long, or is blotched with large patches of feldspar crystals.. The feldspar is orthoclase and coarse microcline."

C. SURFICIAL GEOLOGY

The surficial geology of the Merrimack Valley RPA Area has been described on various U. S. Geological Surficial Geology Quadrangle Maps (Castle, 1958, 1959; Oldale, 1962; Sammel, 1963; Cuppels, 1969), U. S. Geological Survey Groundwater Supply papers (Sammel, Baker & Brackly, 1966; Sammel, 1967), a U. S. Geological Survey - Mass. Dept. of Public Works Bulletin (Chute & Nichols, 1941) and the U. S. Dept. of Agriculture Soil Survey of Essex County (1925). Particulars of the information used to prepare this report may be found by consulting Index Map I1. In addition, several studies in adjoining New Hampshire areas have been consulted. (Goldthwait, Goldthwait & Goldthwait, 1951; Bradley, 1964).

The unconsolidated deposits of the Merrimack River Area are primarily composed of glacial debris left behind by the passage of one or more continental ice sheets during the Pleistocene Epoch. Pleistocene marine clays as well as wind-laid deposits, swamp and marsh deposits and alluvium of recent age constitute the remainder of the unconsolidated materials found in the area. With the exception of the marine clays and marsh deposits, the same statement may be made for any of the other four RPA Areas.

A brief discussion of the regional surficial geologic history is included earlier in this report. Here we will deal with the particular unconsolidated materials occurring in this RPA Area.

Bedrock Surface

The relief and configuration of the bedrock surface determines, to a certain degree, the thickness of sediments found in the area. The deepest deposits are found in pre-glacial stream valleys which have been incised into the bedrock surface. The most significant of these are located on the Groundwater Geology Map W1 included with this text.

A significant relationship between the bedrock and surficial geology in northeastern Essex County has been described by Shride (in Goldsmith & Page, 1973, p. 15).

" Correlation of bedrock and surficial geology in environmental appraisals (or) Surficial deposits related to bedrock in northeastern Massachusetts

Mapping in the Newburyport West and adjacent quadrangles of northeastern Essex County, Mass., has shown that the thicknesses and characteristics of glacial and glaciofluvial deposits south of the Merrimack River closely reflect the underlying bedrock. Three couplings of surficial deposits to bedrock, oversimplified in this brief description, illustrate the kinds of associations widely seen. Phyllite underlying most of the town of West Newbury resisted glacial scour and now cores a plateau that stands somewhat above terrains to the east and south. Drumlins of very clayey till locally derived from the phyllite surmount much of the plateau; away from the drumlins through broad areas the till is only inches thick; even so, phyllite outcrops are scant. Sand and gravel are practically absent; soils are thin, groundwater lacking, and waste disposal difficult due to impervious till and bedrock. Immediately to the east, in contrast, saussuritized granitoid rocks were gouged away to form a lowland site for the accumulation of gravelly and sandy outwash deposits, which may cover the bedrock to considerable depths and do provide sites for water wells and for gravel quarries. Little of the detritus scoured from the bedrock remains. South of the areas of phyllite and granitic rock, a two-mile wide high-standing rib of fine-grained diorite and associated resistant formations furnish granular fines and coarse detritus locally heaped in large amounts. Bedrock of the rib is widely exposed and soils are so thickly strewn with erratics as to discourage land development through much of the area. Compared with the phyllite area, drumlins and till deposits are sparse in both plutonic terrains, but in certain other bedrock terrains farther south drumlins are again characteristic. These illustrations, from studies by A. F. Shride, indicate that more satisfactory conclusions on geologic factors which require assessment in connection with land-use studies in this area are possible if data from bedrock and surficial geology are considered in combination."

Glacial Till

Till is exposed in about one-half of the report area. It is composed primarily of the unsorted rock and soil spread over the land by the last glacial advance. In this form it constitutes ground moraine, a generally thin and irregular layer. Till also occurs as drumlins--rounded elongate hills found throughout the area. The thickness of the till in these landforms may exceed one hundred feet. According to Alden (1924, pl. 13) many drumlins occur north of the Merrimack River in Merrimac, Haverhill and Methuen.

Typically glacial till includes a wide range of particle sizes from clay through boulder sizes. It is generally unstratified, dense, and exhibits low permeability. The deeper till deposits often include two zones: an upper sandy zone which is yellowish-brown in color and a lower gray colored zone which includes more clay and silt-size particles and is usually more compact or dense. Cobbles and boulders occur in both types, although they appear to be more numerous in the looser sandier variety. Layers or lenses of stratified sands, silts and even varved silts and clays are sometimes embodied in the till, but these zones are usually limited to small local occurrences.

The USDA Soil Series report and map for Essex County was utilized in mapping portions of this RPA Area. Areas described as Brookfield, Charlton, Coloma, Essex, Gloucester, Hollis, Hinsdale, Sutton, Whitman, and Woodbridge soils are mapped as Glacial Till.

Outwash and Ice Contact Deposits

Extensive deposits of "clean" sand and gravel occur in the eastern portion of the area. Chute and Nichols (1941, p. 13 & 14) refer them to kames, kame terraces, and outwash deposits and describe their occurrence:

> " The other unusual kame area underlies the city of Newburyport and extends beyond it to the northwest and southeast. This long ridge-like deposit is the southern end of what Keith and Katz described as part of the Newington moraine. As far as can be determined from surface observation, the deposit is composed entirely of sand and gravel. No till was seen in the road cut at the southeastern end of the city or in any of the other pits and cuts in the deposit...At the south side of the city of Newburyport, in the Oak Hill cemetery area, the topography is characterized by knobs and basins and is more kame-like than elsewhere. The ridge is widest northwest of Newburyport and locally has a broad nearly flat top pitted in places by kettle holes. Much of the southwest side of the deposit is bounded mostly by relatively steep slopes that strongly suggest ice contact slopes. The northeast side is also steep but it is adjacent to the Merrimack River for most of its length and doubtless has been modified by river erosion. The writer is inclined to believe that the deposit is the filling of a large crevasse in the ice and prefers to map it as kames until more evidence is available."

"Outwash plains are extensive in this area. Some show certain complexities such as terracing and irregularities of topography that require detailed study for adequate interpretation. For example, a second terrace is easily discernible below the kame terrace that rims Batt Hill in Salisbury. This lower terrace stands about 20 feet above the main outwash plain and is probably also a kame terrace."

Elsewhere ice contact and outwash deposits are distributed from place to place throughout the report area. They underlie large portions of Andover, Boxford, Groveland and Georgetown, where they constitute the major water bearing strata.

Outwash and ice contact deposits are treated together here, although in a geological sense, they are separable. Materials comprising the two types of deposits are similar. For the most part they include sands, and sands and gravels. In places beds of silt occur, as do layers of "peastone" size gravel and cobble beds. In general the ice contact and/or outwash deposits are stratified and sorted; they are usually highly permeable.

The Essex County USDA Soil Series Report maps ice contact and outwash materials as Hinckley and Merrimack soils.

Glacial Lake Bottom Deposits

Glacial lake bottom deposits are the finer-grained deposits which accumulated in temporary lakes supplied by glacial meltwaters. Mapping techniques used today separate the areas of lake bottom deposits from the coarser-grained stratified sediments. But, unfortunately, earlier workers often did not. Thus the extent of these finer-grained deposits, either within the mapped limits of outwash and ice contact deposits or among USDA soil group delineations, is unknown.

Only one small area, in Methuen, has been mapped as lake bottom deposits. These are described by Castle (1958) as "Lake bottom and Shoreward deposits glacial Lake Methuen", and;

"...A large part of the northwestern section of the quadrangle was covered by a lake in late Pleistocene time. This lake has been named glacial Lake Methuen, in this report, after the town in which the lake deposits occur. The bottom deposits, consisting almost entirely of fine sand, silt, and clay, exceed 15 feet in thickness. No varves have yet been discovered among the sediments of glacial Lake Methuen."

Marine Clays

Marine silty clays and silts underlie lowlands in the coastal area and in the river valleys and tributaries of the Merrimack, Parker and Ipswich Rivers for a distance of five to ten miles inland. They occur at elevations up to 80 feet, having been deposited during a rise in sea level which accompanied deglaciation in the area. Their mapped extent includes major portions of Newbury, Newburyport and Rowley and lesser parts of Salisbury, West Newbury and Georgetown.

The thickness of the marine clays varies from less than five feet to more than fifty feet. At several locations the deposit occurs directly over either till or bedrock, but it is also reported to overlie outwash deposits in certain areas.

The clay is somewhat bedded, silt and/or sandy silt layers occurring in the upper portions of the strata. However, its overall character is that of a fine-grained, relatively impermeable deposit.

In Essex County, the USDA report describes the Orona and Palmyra soils as originating from "heavy clays laid down under marine conditions."

Marine Organic Soils

Marine marsh deposits occupy lowland coastal regions and estuaries. They occur in Salisbury, Newburyport, Newbury and Rowley. Hartwell (1970, p. 163) reports that the sediments and plants comprising the present-day marsh system have been accumulating in those areas for several thousand years. The soils found here include clayey organic silts, marine peats and a variety of organic sand-silt and clay combinations. All are generally fine grained and impervious.

Fresh Water Organic Soils

Scattered fresh water swamp deposits occur in poorly-drained upland areas consisting of bedrock or glacial till, and in greater numbers along the valley floors among alluvial and outwash deposits. Relatively large areas in Georgetown, Groveland, Boxford and North Andover are occupied by fresh water swamp deposits. Wherever ice contact deposits occur, the kettle hole depressions are often partially filled with peat and other organic soils.

The thickness of the fresh water organic soil deposits is variable. In upland areas underlain by till or bedrock, the organics are most often shallow, rarely exceeding a few feet in average depth. However, in ice contact deposits, particularly in kettles, the deposits may be twenty to forty feet thick.

The composition of the organics is also variable: anything from fibrous, partially decomposed vegetable matter to slightly organic sands and silts may be expected. In most cases the thicker deposits are also highly organic.

Dune and Beach Sands

Sands of several origins are grouped together under this heading. These include beach sands and dune sands of post-glacial through recent origins, those referred to as marine sands representing deltaic deposits associated with the marine clays, and deposits of wind blown post-glacial sands which intermittently cover the entire area.

The beach and dune sands are located in eastern coastal sections. The outer edge of Plum Island is the most extensive area mapped. Deposits here have been supplied by long-shore drift from the north, and have been blown into dunes that reach fifty feet or more in height. These materials are generally well-sorted fine to medium sands.

The marine sands represent either a post-glacial near-shore deltaic deposit related to the marine clays described above, or modifications of those sands which are ancient dunes and/or shores. They are displayed most prominently along a strip one to two miles west of the coast. The sands here are also well sorted and of fine to medium size (.05 to .5 millimeters).

The following description of the origin and occurrence of other wind blown deposits in the area is taken from Castle (1958):

> " Apparently a time lag occurred between the disappearance of the ice and the growth of an extensive cover of vegetation, for a thin blanket of wind-blown deposits covers much of southern New England. These deposits characteristically are composed of unstratified, dusky-yellow, fine to medium sand. The thickness of the wind-blown deposits averages from 1 foot to 2 feet and generally does not exceed 4 feet... Frost action has mixed the wind-blown and underlying deposits so that the contact between the two is frequently indiscernible."

These soils, being of such a limited thickness, were only mapped in a very few areas.

Alluvium and River Terrace Deposits

Alluvium and river terrace deposits are mapped together in this study. It should be pointed out that the river terraces are in part erosional forms, and therefore may include soils other than those described as typical for this group.

In general the terrace deposits and alluvium occur along post-glacial and recent stream courses; those along the Merrimack and Shawsheen Rivers are the most extensive. The deposits are discontinuous and often thin or lacking altogether. However, along the Merrimack east of Lawrence, a broad and thick flood plain has been constructed complete with three terrace levels and natural levees along its banks. These deposits commonly overlie outwash and/or ice-contact materials and as such, make up a combined unit of coarse-grained soils of considerable thickness.

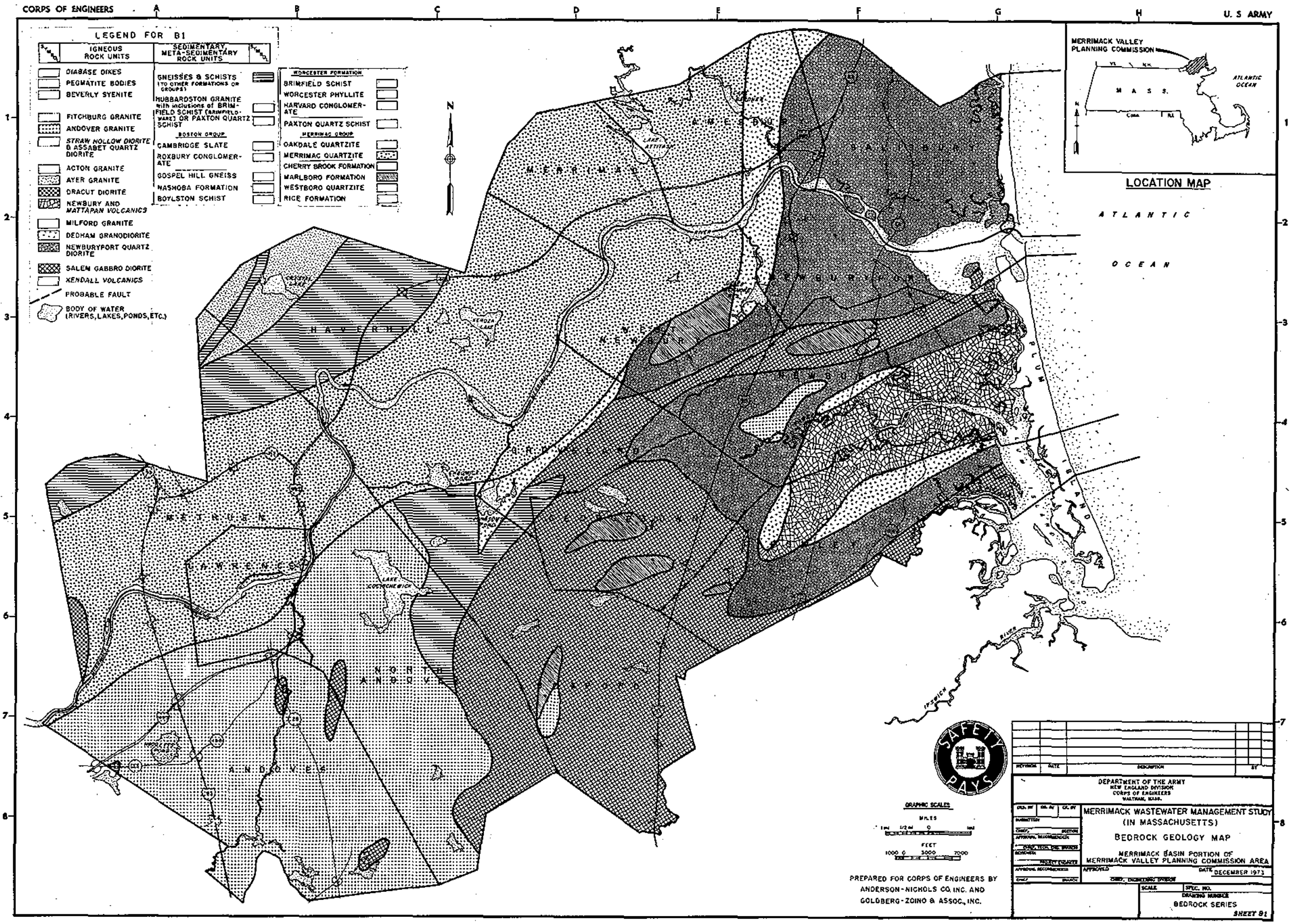
The materials which constitute alluvium deposits include sands, silt, clays and gravels--often as combinations of all four. Minor amounts of organic material may or may not be included. These deposits are generally somewhat loose, poorly sorted, and partially stratified. Their permeabilities vary from place to place. River terrace deposits, where defineable, exhibit higher degrees of sorting and stratification, and are generally pervious.

USDA information maps alluvium deposits in Essex County as the Ondawa very fine sandy loam.

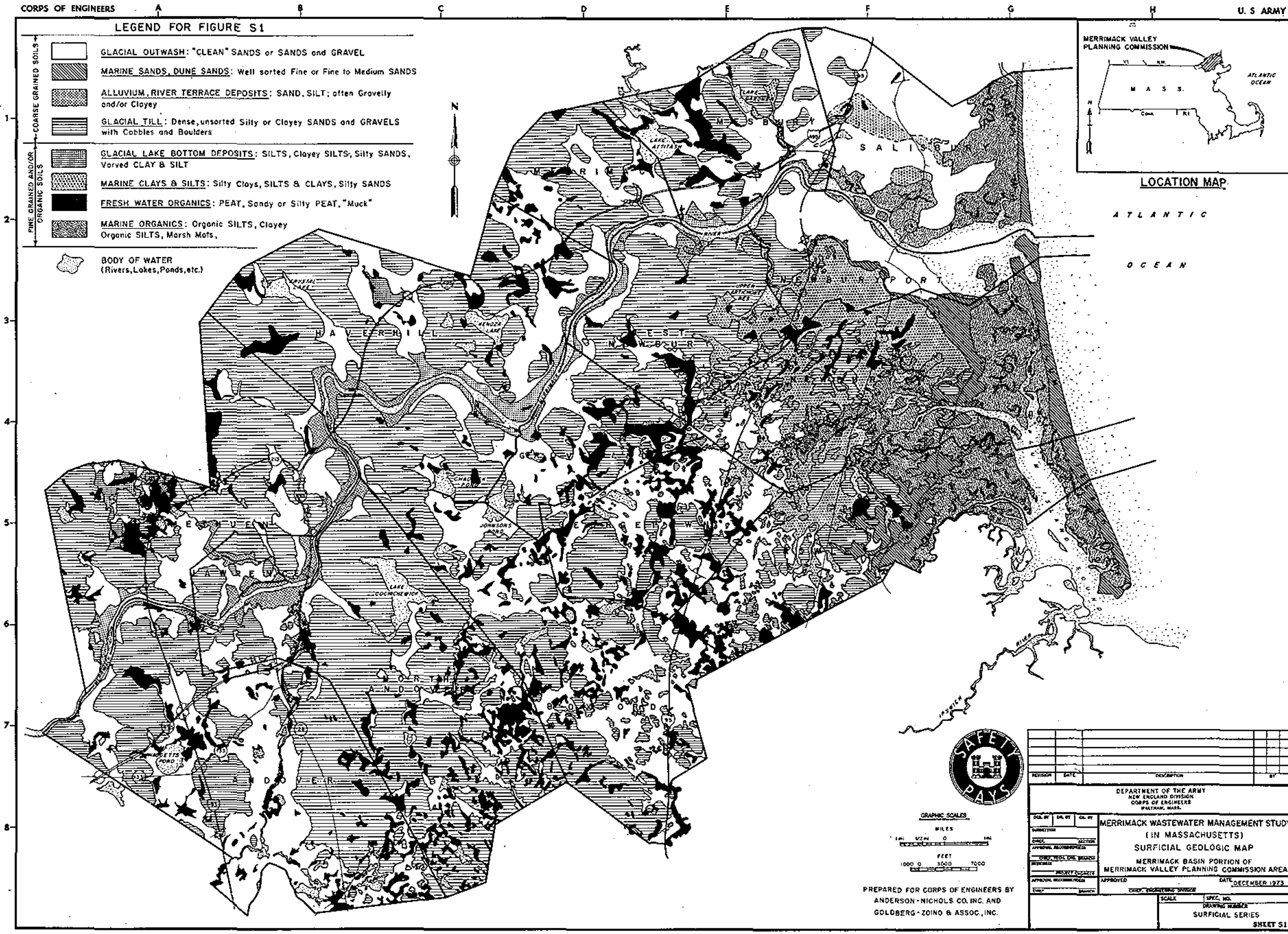
D. GROUND WATER GEOLOGY

Ground water favorability for the northeastern part of the Merrimack River Basin is shown in Figure W1. The entire southwest portion of the map, with the exception of Andover, Massachusetts, has been mapped by the USGS for ground water favorability. That mapping has been transferred to this map and extended into the Merrimack Basin south of the River. Well logs for this area were also reviewed in the USGS offices for those areas without published maps.

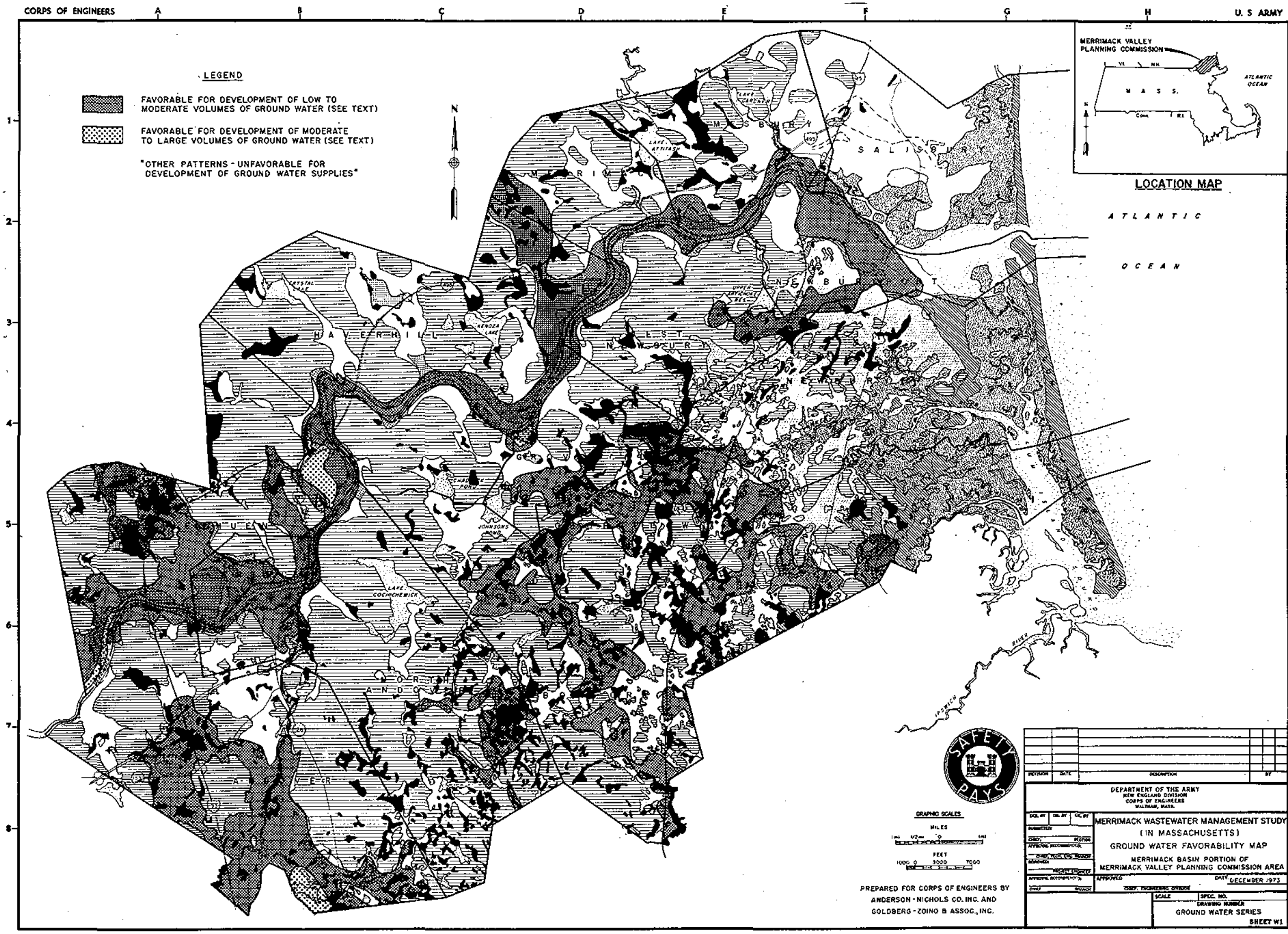
Several highly favorable areas for development of ground water were identified from the well logs. These are:



CORPS OF ENGINEERS
U. S. ARMY
LEGEND FOR B1
IGNEOUS ROCK UNITS
DIABASE DIKES
PEGMATITE BODIES
BEVERLY SYENITE
FITCHBURG GRANITE
ANDOVER GRANITE
STRAW HOLLOW DIORITE & ASSABET QUARTZ DIORITE
ACTON GRANITE
AYER GRANITE
DRACUT DIORITE
NEWBURY AND MATTAPAN VOLCANICS
MILFORD GRANITE
DEDHAM GRANODIORITE
NEWBURYPORT QUARTZ DIORITE
SALEM GABBRO DIORITE
XENDALL VOLCANICS
PROBABLE FAULT
BODY OF WATER (RIVERS, LAKES, PONDS, ETC.)
SEDIMENTARY, META-SEDIMENTARY ROCK UNITS
GNEISSES & SCHISTS (TO OTHER FORMATIONS OR GROUPS)
HUBBARDSTON GRANITE with inclusions of BRIMFIELD SCHIST (BRIMFIELDWARE) OR PAXTON QUARTZ SCHIST
BOSTON GROUP
CAMBRIDGE SLATE
ROXBURY CONGLOMERATE
GOSPEL HILL GNEISS
NASHOBA FORMATION
BOYLSTON SCHIST
WORCESTER FORMATION
BRIMFIELD SCHIST
WORCESTER PHYLLITE
HARVARD CONGLOMERATE
PAXTON QUARTZ SCHIST
MERRIMAC GROUP
OAKDALE QUARTZITE
MERRIMAC QUARTZITE
CHERRY BROOK FORMATION
MARLBORO FORMATION
WESTBORO QUARTZITE
RICE FORMATION
N
MERRIMACK VALLEY PLANNING COMMISSION
VT.
N.H.
MASS.
Conn.
R.I.
ATLANTIC OCEAN
LOCATION MAP
ATLANTIC
OCEAN
AMESBURY
SALISBURY
MERRIMAC
NEWBURYPORT
HAVERHILL
WEST NEWBURY
NEWBURY
GROVELAND
METHUEN
LAWRENCE
NORTH ANDOVER
ANDOVER
BOXFORD
GEORGETOWN
ROWLEY
PLUM ISLAND
LAKE COCHICHEWICK
KENOZA LAKE
LAKE ATTITASH
IPSWICH RIVER
SAFETY PAYS
GRAPHIC SCALES
MILES
FEET
1000 0 3000 7000
PREPARED FOR CORPS OF ENGINEERS BY
ANDERSON-NICHOLS CO. INC. AND
GOLDBERG-ZOINO & ASSOC., INC.
REVISION
DATE
DESCRIPTION
BY
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)
BEDROCK GEOLOGY MAP
MERRIMACK BASIN PORTION OF
MERRIMACK VALLEY PLANNING COMMISSION AREA
APPROVED
DATE DECEMBER 1973
SCALE
SPEC. NO.
DRAWING NUMBER
BEDROCK SERIES
SHEET B1



CORPS OF ENGINEERS
U. S ARMY
LEGEND FOR FIGURE S1
COARSE GRAINED SOILS
GLACIAL OUTWASH: "CLEAN" SANDS or SANDS and GRAVEL
MARINE SANDS, DUNE SANDS: Well sorted Fine or Fine to Medium SANDS
ALLUVIUM, RIVER TERRACE DEPOSITS: SAND, SILT; often Gravelly and/or Clayey
GLACIAL TILL: Dense, unsorted Silty or Clayey SANDS and GRAVELS with Cobbles and Boulders
FINE GRAINED AND/OR ORGANIC SOILS
GLACIAL LAKE BOTTOM DEPOSITS: SILTS, Clayey SILTS, Silty SANDS, Varved CLAY & SILT
MARINE CLAYS & SILTS: Silty Clays, SILTS & CLAYS, Silty SANDS
FRESH WATER ORGANICS: PEAT, Sandy or Silty PEAT, "Muck"
MARINE ORGANICS: Organic SILTS, Clayey Organic SILTS, Marsh Mats,
BODY OF WATER (Rivers, Lakes, Ponds, etc.)
N
MERRIMACK VALLEY PLANNING COMMISSION
M A S S.
ATLANTIC OCEAN
LOCATION MAP
A T L A N T I C
O C E A N
SALISBURY
NEWBURYPORT
HAVERHILL
WEST NEWBURY
METHUEN
LAWRENCE
NORTH ANDOVER
ANDOVER
LAKE COCHICHEWICK
JOHNSONS POND
GRAPHIC SCALES
MILES
FEET
PREPARED FOR CORPS OF ENGINEERS BY
ANDERSON-NICHOLS CO. INC. AND
GOLDBERG-ZOINO & ASSOC., INC.
REVISION
DATE
DESCRIPTION
BY
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)
SURFICIAL GEOLOGIC MAP
MERRIMACK BASIN PORTION OF
MERRIMACK VALLEY PLANNING COMMISSION AREA
APPROVED
DATE DECEMBER 1973
SCALE
SPEC. NO.
DRAWING NUMBER
SURFICIAL SERIES
SHEET S1



CORPS OF ENGINEERS
U. S. ARMY
LEGEND
FAVORABLE FOR DEVELOPMENT OF LOW TO MODERATE VOLUMES OF GROUND WATER (SEE TEXT)
FAVORABLE FOR DEVELOPMENT OF MODERATE TO LARGE VOLUMES OF GROUND WATER (SEE TEXT)
"OTHER PATTERNS - UNFAVORABLE FOR DEVELOPMENT OF GROUND WATER SUPPLIES"
N
MERRIMACK VALLEY PLANNING COMMISSION
MASS.
ATLANTIC OCEAN
LOCATION MAP
ATLANTIC
OCEAN
SALISBURY
MERRIMAC
HAVERHILL
WEST NEWBURY
NEWBURYPORT
NORTH ANDOVER
ANDOVER
LAKE ATTITASH
KENOZA LAKE
JOHNSONS POND
LAKE COCHICHEWICK
GRAPHIC SCALES
MILES
FEET
PREPARED FOR CORPS OF ENGINEERS BY
ANDERSON-NICHOLS CO. INC. AND
GOLDBERG-ZOINO & ASSOC., INC.
SAFETY PAYS
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)
GROUND WATER FAVORABILITY MAP
MERRIMACK BASIN PORTION OF
MERRIMACK VALLEY PLANNING COMMISSION AREA
DATE DECEMBER 1973
GROUND WATER SERIES
SHEET W1

1. In northwest Groveland near the Merrimack River.

2. In the eastern, west-central, and southern parts of Methuen.

3. In the south part of Andover.

Several areas of stratified drift which would ordinarily have been mapped as intermediately favorable were mapped as unfavorable because of the low volume capability of wells in the area. These include:

1. Extensive stratified drift areas north of the Merrimack River.

2. An area surrounding Johnson's Pond near the center of the map.

3. An extensive area in north-central and western Andover.

The quality of ground water, particularly in the lower reaches of the Merrimack River where an intermediate favorability is indicated, should be carefully evaluated before using this map as a guide for development.

The ground water favorability mapping for the area shown on Figure W1, particularly in terms of highly favorable areas, should be considered incomplete along the river courses. Insufficient well-log data is the main reason for the lack of completeness, since the highly porous materials along most rivers should be favorable for ground water supply development.

2. NORTHERN MIDDLESEX AREA COMMISSION

A. LOCATION, TOPOGRAPHY AND DRAINAGE

The Northern Middlesex RPA Area is situated in the northern portion of Middlesex County. Its bounds are: the New Hampshire state line on the north, the towns of Methuen and Andover on the east, the towns of Wilmington, Burlington, Bedford, Carlisle, Acton and Littleton on the south, and the towns of Groton, Shirley and Townsend on the west.

Most of the report area is located in the Seaboard Lowland sector of the New England physiographic province. Topography here is typified by rounded hills and broad, poorly-drained lowlands. Summits of most hills occur below elevation 400; commonly the relief is less than 200 feet. The westernmost portions are within the New England upland section of the province. In these areas the maximum elevations exceed 500 feet, and the relief often approaches 300 feet.

The area is drained by the Merrimack River and its tributaries. These include the Concord River which joins the Merrimack at Lowell, and the Nashua River whose basin occupies a significant area in north-central Massachusetts. The Nashua merges with the Nissitissit River in Pepperell and flows northeast, joining the Merrimack at Nashua, New Hampshire.

B. BEDROCK GEOLOGY

Various types of igneous and metamorphic rocks are present in the Northern Middlesex RPA Area. These include quartzites, schists and other meta-sedimentaries, as well as granites, granodiorites and diorites of plutonic origin.

The geology of this region has been described by Emerson (1917) and Jahns, Willard, White and Currier (unpublished). In addition to this information, publications by Hansen (1956) and Billings (1956) discuss the geology in this area.

Igneous rock units identified by Emerson include the Dedham Granodiorite, Dracut Diorite, Andover Granite and Ayer Granite. Of these the Dedham Granodiorite has been assigned to a pre-Cambrian or early Paleozoic age; the remaining units have been assigned to the Paleozoic.

Metamorphic rock units include the Merrimack Quartzite, Oakdale Quartzite, Paxton Schist, Worcester Phyllite, Brimfield Schist, Nashoba Formation and gneisses and schists of undetermined age. All are thought to be of Paleozoic age.

Structural trends in the area are toward the northeast, as they were in the adjoining Merrimack Valley RPA Area. In a general way the outcrop belts of the various meta-sedimentary units and the strike of their foliation bear to the northeast. Large scale regional folding is indicated, and has been discussed by all of the various writers mentioned above. Most of the metamorphic rocks also show many minor folds, as well as evidence of faulting on a major and minor scale. One such fault is mapped by Emerson in Pepperell. Precise structural details in the Upper Middlesex RPA Area will hopefully be provided when the work by Jahns, Willard, White and Currier is published.

METAMORPHIC ROCKS

Merrimack Group - Merrimack Quartzite

Emerson (1917, p. 58-62) correlated the Merrimack Quartzite with the Oakdale Quartzite and Paxton Quartz Schist. Billings (1956, p. 44) maintained this correlation in part, but lumped in portions of Emerson's unassigned gneisses and schists. It appears that the areas in Dunstable, Tyngsborough and Dracut, which Emerson mapped as unassigned, are among those which Billings refers to the Merrimack Group.

Two quoted descriptions follow: both are from Emerson. The first is that of the Merrimack Quartzite as he mapped it in Lowell and Dracut; the second is his description of the unassigned gneisses and schists in the study area.

> " The formation consists chiefly of thin-bedded quartzite or quartz schist, as a rule somewhat actinolitic, generally gray or greenish-gray, but made chocolate-colored at many places by the red biotite which is disseminated in it in small amounts, and at other places stained rusty brown by the oxidation of pyrite. At many places there are thin intercalated beds of slate or slaty quartz schist, and at others there are thin lenses and roundish nodules of greenish calcareous or epidotic rock, exactly as in the Oakdale quartzite.
>
> The rock is in general more massively quartzitic toward the northwest side of the belt and more slaty toward the southeast side, and seems to show a progressive increase in its slaty character northeastward along the strike."

(Emerson, 1917, pp. 58 & 59)

" A considerable part of northeastern Massachusetts is occupied by metamorphic rocks--some of igneous and others of sedimentary origin but the two sorts apparently closely associated--whose age has not been definitely determined and is a matter about which opinions differ widely. The principal types are biotitic gneisses and schists of sedimentary origin and biotitic gneisses of probable igneous origin, but a number of other types are included, especially some peculiar injection gneisses and several bodies of highly altered limestone.

The metamorphic rocks here mapped together extend northeastward into New Hampshire and southwestward into Connecticut, and have been mapped and described by several authors and under various names. In northeastern Massachusetts they occupy six rather large continuous areas or belts with a general northeast-southwest trend......

....On the northwest a large area extends from Ayer northeastward into New Hampshire and probably across that State into southwest Maine. A smaller belt, parallel to the last, extends from Merrimack River near North Chelmsford northeastward past Haverhill into Newton, New Hampshire....

The rocks of the several areas differ somewhat in character, especially in the ratio of rocks believed to be sedimentary to those regarded as igneous but approximately contemporaneous with the sediments. In the northern areas sedimentary rocks appear to predominate over igneous rocks."

(Emerson, 1917, p. 78 - 79)

Oakdale Quartzite

The Oakdale Quartzite is found in western portions of the area, primarily in Pepperell. Billings maps the northward extension of these rocks with the Merrimack group. They are described by Emerson (1917, p. 61):

" The Oakdale quartzite is named from Oakdale, a village in the town of Sterling, Mass., where it is conspicuously displayed. It is the least altered of the older Carboniferous formations and retains many of its sedimentary characters but grades into more crystalline varieties. It is a fine, even-grained, flaggy quartzite, in many places greatly jointed, reddish-brown from the development of secondary biotite in minute scales or greenish from the development of actinolite in small lenses or subordinate beds that were originally calcareous. It contains accessory menaccanite, ottrelite, pyrite, and muscovite. The bedding and the quartz grains are in many places original. Near the granite intrusions the quartz grains are enlarged or wholly recrystallized, the whole mass is coarser grained, and the rock grades into the next type."

Paxton Quartz Schist

Emerson's (1917, p. 62) Paxton Quartz Schist occupies a small area in northwest Pepperell. His description includes:

> " Toward the west what I regard as the equivalent of the Oakdale Quartzite is more flaggy, includes more abundant and visible biotite and, in the small green calcareous areas, distinct lenses of actinolite, some of them containing diopside, essonite, titanite, pyrite, and residual calcite. It includes small beds of mica schist and limestone, and some of it is slightly graphitic. This type of rock is called the Paxton quartz schist, from its development at Paxton, northwest of Worcester."

Worcester Formation- Worcester Phyllite

The Worcester Phyllite occupies significant portions of Worcester County to the south, and according to Emerson, extends northward into New Hampshire. Billings (1956, p. 102), with reservations, described this area with the Merrimack group. His statement follows:

> " The large body shown as Worcester phyllite north of Worcester splits into two branches toward the north. One of these, with an increase in the grade of metamorphism, extends northeastward as far as Lowell. Since this branch does not extend into New Hampshire it need not concern us further. The other branch extends north to the state boundary. On the geological map of New Hampshire the continuation of this belt is shown as a phyllite member of the Merrimack group. But if Emerson's age determinations and correlations in Massachusetts are correct, it is Worcester phyllite of Pennsylvanian age. If so, the present writer would suggest that the phyllite rests unconformably on the Merrimack group and is downfolded in a small syncline."

The formation, according to Emerson (1917, p. 62-63), includes:

> " ...--In its least changed or typical phase the Worcester phyllite ranges from soft black slate or phyllite, partly carbonaceous and partly graphitic to light greasy sericite schist. The rock is thinly fissile, lead gray, with a corrugated satiny surface, generally splitting on the original lamination and not on a secondary cleavage...Its satiny surface is produced by the recrystallization of its clayey material into fine scales of mica, and as these scales grow coarser the rock grades into mica schist. The accessory minerals are biotite, ottrelite, garnet, pyrite, and minute chiastolite."

Worcester Formation - Brimfield Schist

Emerson's Brimfield Schist has been described as the "mica schist facies" of the Worcester Formation, and the stratigraphic equivalent of the Worcester Phyllite (Hansen, 1956, p. 20). Billings evidently also shared this viewpoint inasmuch as the area he mapped and referred to in the quote cited above very nearly corresponds to Emerson's branching area of Brimfield Schist near Lowell.

Emerson's (1917, p. 68-69) description follows:

> "......--The Brimfield schist is the most marked and most widely distributed of the metamorphic formations assigned to the Carboniferous. The rock is a uniform coarse red-brown muscovite schist containing much biotite, fibrolite (commonly derived from an antecedent andalusite), and graphite, and so much pyrite that it is wholly rusted in many of the deepest openings. It forms deep brown soils and abundant efflorescence of copperas, formerly used for dyeing, and names like Dyestone Rock, Alum Pond, and Copperas Hill are common. The formation was named for its occurrence at Brimfield, Mass."

Nashoba Formation

The Nashoba Formation was described by Hansen (1956, p. 31) from rocks exposed in the Maynard and Westford Quadrangles.

" The name Nashoba formation is proposed for a great mass of metamorphic rocks of Carboniferous age that extends northeastward across east-central Massachusetts almost from Connecticut to New Hampshire. The name is proposed because of the occurrence and good exposure of these rocks in the valley of Nashoba Brook in the Maynard and Westford quadrangles. They are probably best exposed in the town of Bolton, and the name Bolton gneiss was originally applied to them by Emerson (1917, p. 81); he abandoned this appropriate name, however, as it had been preoccupied for a different formation elsewhere."

Their regional extent is best mapped by Billings (1956, p. 100) who at that time retained the descriptive name of "Bolton" gneiss. Both Hansen and Billings used a Carboniferous age for this unit, but recent workers now consider the Nashoba Formation to be of a pre-Silurian age (Bell, et al., in Goldsmith & Page, 1973, p. 12).

Emerson (1917, p. 81) describes his "Bolton" gneiss as follows:

" The 'Bolton' gneiss is typically exposed in the town of Bolton and Berlin. It consists as a rule of well-banded mica gneiss, with layers made up of coarse muscovite, biotite, and quartz alternating with more quartzose and feldspathic layers. The commonest type is a medium-grained to fine-grained quartzose biotite gneiss of gray or brown color, in some places containing graphite, fibrolite, and garnet. The rock splits into layers 3 to 4 inches thick and makes good flagging. Layers and lenses of quartz and of several pegmatites are common and in places make up much of the rock. They include greisen as well as the more common feldspathic pegmatite, and some are much squeezed and schistose. Other intrusive rocks are numerous dikes and sheets of granite (chiefly Ayer and Andover) and of aplitic and dioritic rocks. The latter are generally more or less foliated."

IGNEOUS ROCKS

Generalized description of the Dedham Granodiorite, Ayer Granite and Andover Granite were provided earlier (p. 19-20, 21-22. They will not be repeated here.

Dracut Diorite

The Dracut Diorite is mapped in northeastern portions of the report area, primarily in Lowell and Dracut where it crosses into New Hampshire. Billings (1956, p. 66) refers to these rocks and tentatively places them in the Devonian period.

Emerson, who named the rock unit, describes it as follows (1917, p. 221 to 222):

> " The name Dracut diorite, taken from the town of Dracut, north of Lowell, is applied to a dioritic rock, with associated tonalitic and noritic phases, which seems to be closely related to the Ayer granite.
>
> The rock displays considerable diversity of character and possibly some rocks not properly belonging in the formation have been included with it in mapping. The commonest and most widely distributed type is a moderately coarse grained biotitic granodiorite or quartz diorite, which generally contains subordinate augite or hypersthene and in many places some hornblende, and which shows a strong tendency toward a foliated or gneissic structure. This phase grades on the one hand into rather fine grained hornblende diorite, in most places rather definitely banded or schistose, and on the other hand into medium-grained norite or hypersthene gabbro, having a subporphyritic texture with crystal or crystalline aggregates of hypersthene, augite, or hornblende, and biotite, in a finer-grained groundmass."

C. SURFICIAL GEOLOGY

Information used in mapping the surficial geology of the Upper Middlesex RPA Area included U.S. Geological Survey Surficial Geology Quadrangle Maps (Castle, 1958, 1959; Koteff & Volckmann, open file, 1972), a U.S. Geological Survey Water Supply paper (Baker, 1964) and the U.S. Department of Agriculture Soil Survey of Middlesex County (1924). Also studies in adjacent areas in New Hampshire were examined (Goldthwait, Goldthwait & Goldthwait, 1951; Bradley, 1964).

Unconsolidated deposits in the Upper Middlesex RPA Area consist of unstratified and stratified glacial drift of Pleistocene age; and freshwater swamp deposits, alluvium, and river terrace deposits of recent age. The stratified glacial drift has been divided into two units for this report; coarse-grained or granular glacial outwash which includes ice contact deposits, and finer grained glacial lake bottom deposits. Alluvium and river terrace deposits will be treated together as one unit.

Bedrock Surface

Bedrock elevations in the report area vary considerably more than the topographic relief. Rock at or below sea level elevation is known to occur below buried valleys in the Lowell area, while near Pepperell in the upland section, bedrock outcrops occur above elevation 500. Baker's

(1964, p. 11) discussion of the buried pre-glacial Merrimack River is appropriate here.

> " The main pre-glacial valley in the Lowell area is the relatively deep, broad valley of the pre-glacial Merrimack River....
> .....Pre-glacial tributary valleys are not well defined but appear to coincide generally with the valleys of Stony Brook, River Meadow Brook, and the Concord River. A pre-glacial valley may coincide with the valley of Beaver Brook also.
>
> From the northwestern corner of the Lowell area to the mouth of Stony Brook at North Chelmsford, the valley of the pre-glacial Merrimack coincides generally in position with the present Merrimack valley. The deepest test well within this reach penetrated to a point 6 feet above sea level without reaching bedrock (well Chelmsford 136). From the mouth of Stony Brook the pre-glacial valley trends southeastward to River Meadow Brook, where it bends sharply to the northeast It can be traced along the valley of River Meadow Brook from the junction of Highways 3 and 110 at least to the vicinity of well Lowell 96 in the Cook Well Field in Lowell. The deepest test well within this reach penetrated to a point 4 feet above sea level without reaching bedrock (well Chelmsford 264), and seismic data (Lee and others, 1940, figs. 10-12) indicate that the bottom of the pre-glacial valley is at or slightly below sea level.
>
> The location and extent of the pre-glacial Merrimack valley beyond the Cook Well Field in Lowell are unknown. W.O. Crosby (1899, p. 302) suggested that the pre-glacial Merrimack River flowed southeastward from the Lowell area and into Boston Harbor by way of the present Mystic valley. This hypothesis was accepted by I.B. Crosby (1937, p. 57; 1939, p. 375-376) who also suggested as an alternate route for the pre-glacial Merrimack across Wilmington (adjacent to the Lowell area on the east) and eastward towards Salem."

Glacial Till

Glacial till underlies approximately 50 percent of the Upper Middlesex RPA Area. The till occurs either as a thin, more or less continuous layer of ground moraine, or as widely scattered drumloid hills where much thicker deposits may be expected. Koteff and Volckmann map an "olive brown, compact blocky till underlying gray till". They suggest that this material may represent a separate period of glaciation (USGS, open file, 1973).

The glacial tills found in this area resemble those found elsewhere, the possible exceptions being the composition of the materials they embody. To a certain degree, tills will be comprised of rock fragments of local origin and thereby crudely reflect the rock type in the region. This area is underlain by a variety of metamorphic and igneous rocks, in particular the Nashoba Formation (Emerson's "Bolton" gneiss), granites, diorites and minor amounts of various meta-sedimentaries. Consequently the tills in the area might be expected to include substantial portions of these rock types. The USDA Middlesex County Soils Survey (1925, p. 13) classifies many of the till derived soils in the area as belonging to the Gloucester series. They state:

> " The soils of the Gloucester series have brown topsoils and yellowish-brown subsoils that become paler with depth and grade, at a depth of about 2 feet, into the gray, unweathered, light-textured, drift parent material. There is no marked textural profile. The soils are derived mainly from granite and gneiss material. They occur on well-drained uplands and carry a noticeable quantity of rounded and subangular stone."

Outwash and Ice Contact Deposits

Thick ice contact deposits exist in the Lowell region, their greatest extent occupying the preglacial channel of the Merrimack River. Similar deposits are reported along the Shawsheen River valley and the south shore of the Merrimack near Lawrence. Extensive amounts of sand and gravel were also found in Pepperell, as deposits laid down in contact with or beyond ice masses in glacial lakes Nashua and Nissitissit. These materials, as well as those seen near Lowell and Lawrence, often occur with or among glacial outwash deposits. Baker (1964, p. 16 & 18) aptly describes the relationships between the two types of deposit and compares their characteristics:

> " Ice-contact deposits are identified principally on the basis of landforms, but other distinguishing characteristics include stratification, sorting, and smoothness and roundness of component particles. At some places the ice-contact deposits cannot be differentiated from the outwash and alluvium with surety. The landforms of the two units are not everywhere distinctive, particularly with respect to the lowest terraces, and the internal characteristics of both units may be similar. Where a well penetrates both units, identification in the subsurface is especially difficult.

Ice-contact deposits are composed of sorted and stratified sand and gravel and subordinate amounts of silt, clay, and stray boulders. The contacts between beds of different grain size are usually sharp, and individual beds rarely extend laterally for more than a few tens of feet. Crossbedding and cut-and-fill structures are common, and deltaic bedding is fairly common. The bedding may be distorted in places where a supporting wall of ice has melted and allowed a deposit to collapse. Where distorted beds are exposed, they are a good criterion for the recognition of these deposits."

" The outwash and alluvium unit consists mostly of sand and subordinate amounts of gravel and silt derived from the glacier and possibly from older unconsolidated deposits. Except for channel deposits of some existing streams, the outwash and alluvium unit is moderately well sorted and well stratified. In general, it is finer textured and more homogeneous than the ice-contact deposits; however, the younger ice-contact deposts and the oldest outwash are very similar lithologically and cannot readily be differentiated."

Glacial Lake Bottom Deposits

Glacial lake bottom deposits are mapped by Koteff and Volckmann in the Pepperell and Dunstable areas (USGS, open file, 1973). Their presence elsewhere in the report area is probable, but undefined in existing literature.

According to Koteff and Volckmann, lake bottom deposits exist for both glacial lakes Nashua and Nissitissit. In the former instance, these materials occur in a relatively large section of east Pepperell and West Dunstable; they continue along the east side of the Nashua River northward into New Hampshire and southward into Groton. Bottom deposits assigned to glacial lake Nissitissit occupy a much smaller area near the northwestern corner of Pepperell; they extend north into New Hampshire. Both occurrences are found in relatively low, poorly drained areas of little relief. The materials comprising the deposits include stratified silts, sands and varved fine grained sediments.

Fresh Water Swamp Deposits

Fresh water swamps are numerous in the report area, especially so in the areas of ice contact and outwash deposits and among or over glacial lake bottom deposits. They also exist in till areas, but to a much lesser extent. A particularly large area known as Great Swamp occurs near North Tewksbury. Here several hundred acres are underlain by organic soils of various types.

Alluvium and River Terrace Deposits

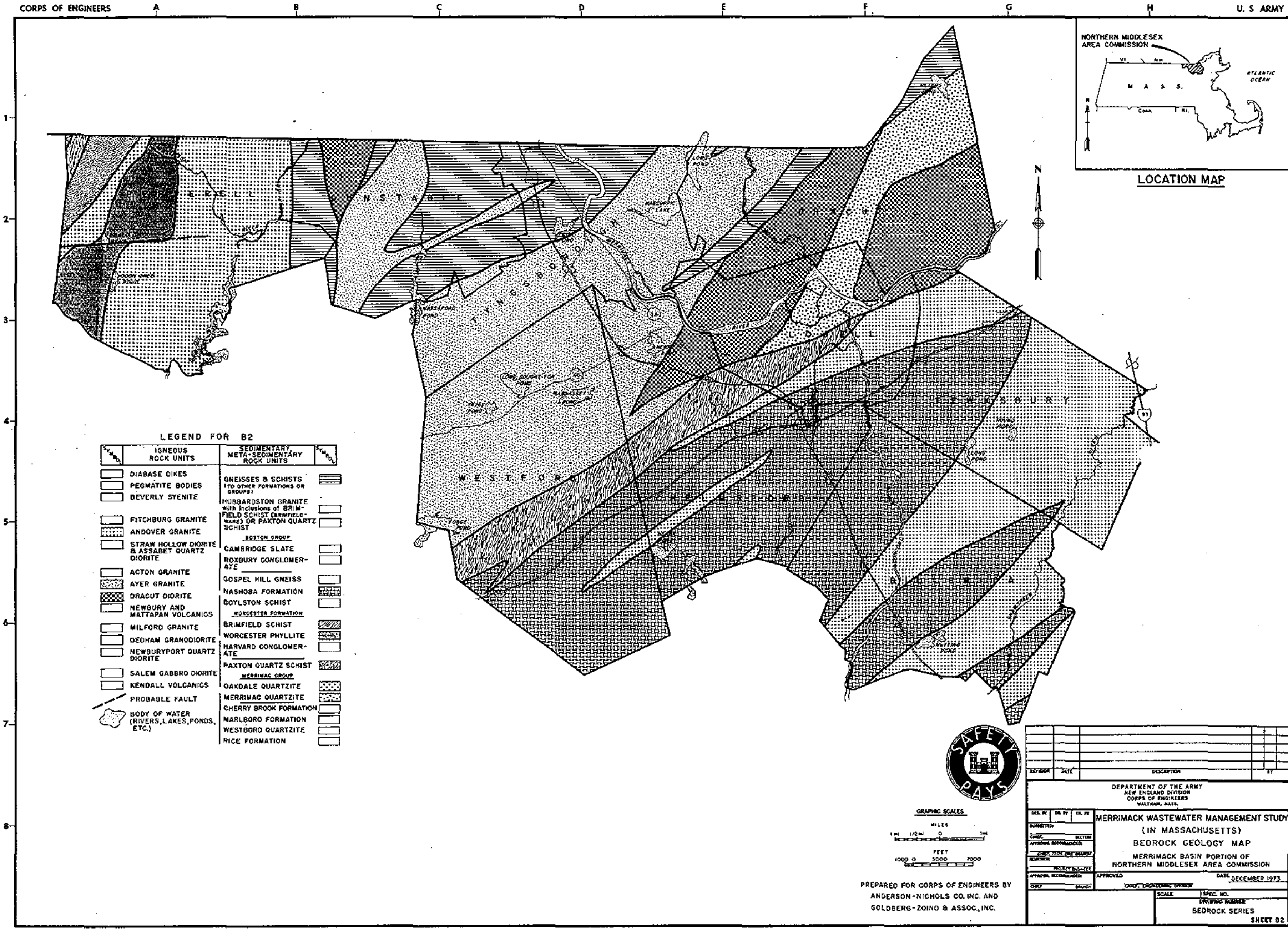
Alluvium, consisting primarily of unconsolidated materials deposited by modern streams, underlies the flood plains and channels of many streams and rivers in the area. Generally older river terrace deposits, derived in part from redeposited outwash materials, were reported along the Nashua, Nissitissit and Merrimack Rivers. Those bordering the Merrimack have been mentioned earlier (see Merrimack Valley RPA) as being of variable extent and thickness.

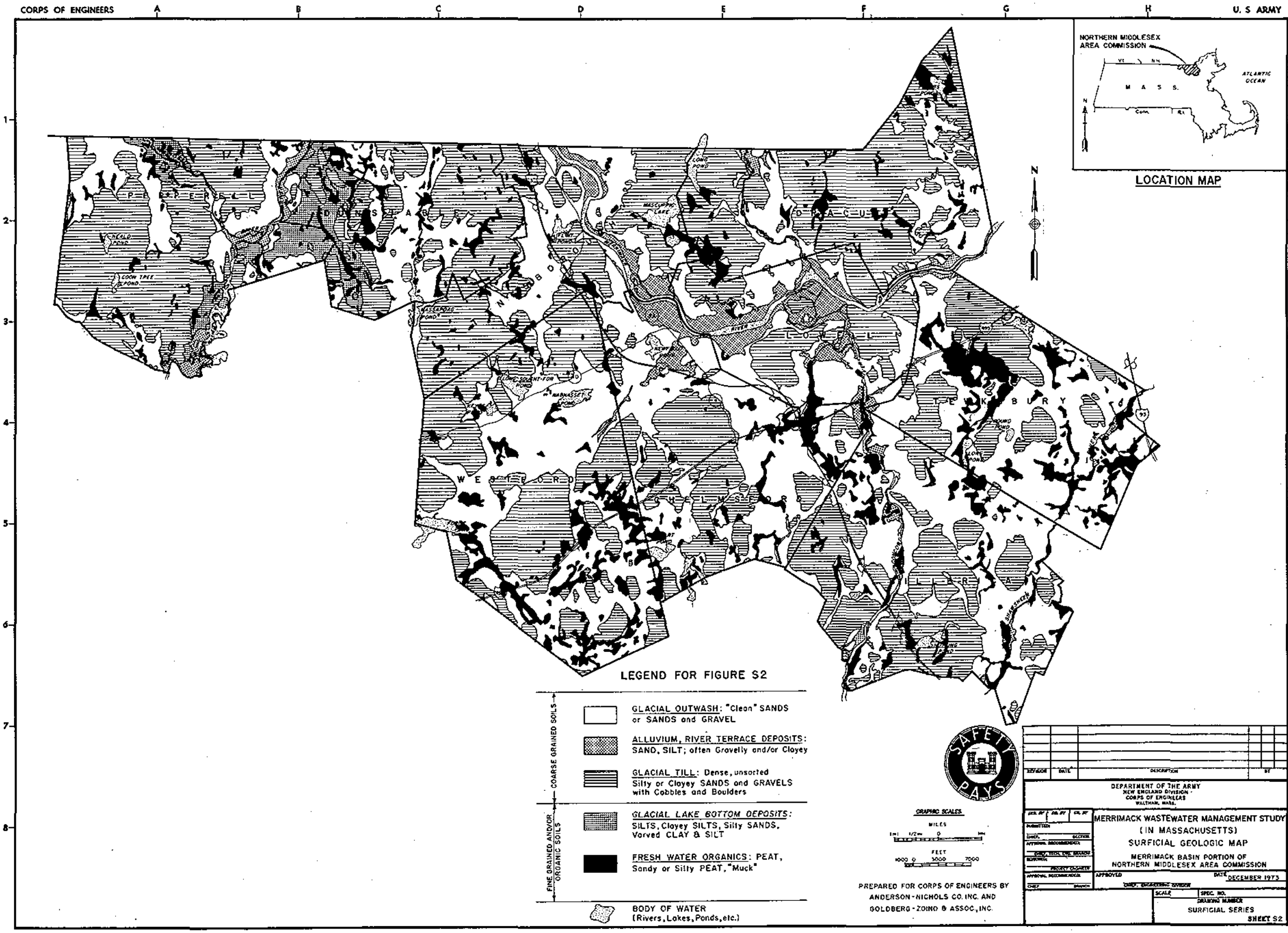
In the Lowell area alluvium and outwash deposits were mapped together (Baker, 1964). Their combined thickness reached 98 feet in one locality. It is assumed that in the context used in this report, much of the deposit would represent outwash. However, caution should be taken before establishing generalities about the thickness and extent of alluvial materials. Castle (1958) points this out in his description of local alluvial deposits in the Lawrence quadrangle.

> " Local alluvial deposits are scattered along many of the minor streams and in lowland sags. Cross sections of these deposits, seen in several excavations, show that in general they are composed of poorly stratified and poorly sorted alluvium with small amounts of organic debris. The extent of these alluvial deposits was considered negligible at first, but observations made immediately after the hurricane of September 11, 1954, showed that along the highland area bordering the west edge of the quadrangle, gullying by the torrential rains had removed hundreds of cubic yards of material from the steeper slopes and redeposited it farther down. This evidence suggests that the area shown as local alluvium on the accompanying map may be underestimated by a major factor, for the contacts between the alluvium and the underlying glacial deposits are commonly obscure."

D. GROUNDWATER GEOLOGY

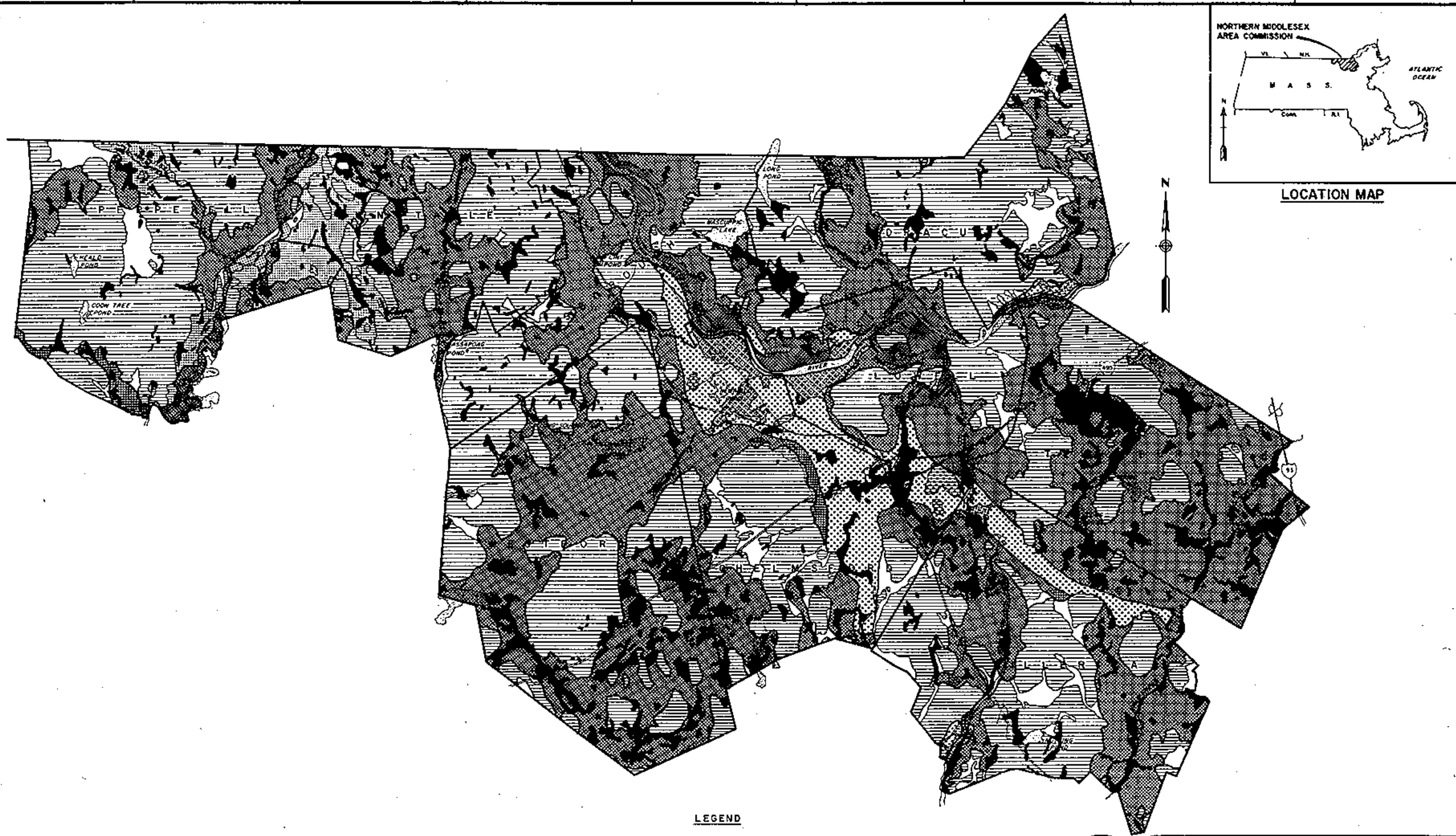
The groundwater favorability for the Northern Middlesex Area Commission part of the Merrimack River Basin is shown in Figure W2. The map patterns shown here are entirely extrapolations of potential ground water favorability on the basis of surficial geological units with the exception of the eastern portion of Dracut where some well log data were reviewed. Depth to bedrock has been partially mapped by both well data and seismic survey in parts of the area (see comments regarding the bedrock surface in preceding sections).


CORPS OF ENGINEERS
U. S. ARMY
NORTHERN MIDDLESEX AREA COMMISSION
MASS.
ATLANTIC OCEAN
LOCATION MAP
N
LEGEND FOR B2
SYMBOL
IGNEOUS ROCK UNITS
DIABASE DIKES
PEGMATITE BODIES
BEVERLY SYENITE
FITCHBURG GRANITE
ANDOVER GRANITE
STRAW HOLLOW DIORITE & ASSABET QUARTZ DIORITE
ACTON GRANITE
AYER GRANITE
DRACUT DIORITE
NEWBURY AND MATTAPAN VOLCANICS
MILFORD GRANITE
DEDHAM GRANODIORITE
NEWBURYPORT QUARTZ DIORITE
SALEM GABBRO DIORITE
KENDALL VOLCANICS
PROBABLE FAULT
BODY OF WATER (RIVERS, LAKES, PONDS, ETC.)
SEDIMENTARY, META-SEDIMENTARY ROCK UNITS
GNEISSES & SCHISTS (TO OTHER FORMATIONS OR GROUPS)
HUBBARDSTON GRANITE with inclusions of BRIMFIELD SCHIST (BRIMFIELDWARE) OR PAXTON QUARTZ SCHIST
BOSTON GROUP
CAMBRIDGE SLATE
ROXBURY CONGLOMERATE
GOSPEL HILL GNEISS
NASHOBA FORMATION
BOYLSTON SCHIST
WORCESTER FORMATION
BRIMFIELD SCHIST
WORCESTER PHYLLITE
HARVARD CONGLOMERATE
PAXTON QUARTZ SCHIST
MERRIMAC GROUP
OAKDALE QUARTZITE
MERRIMAC QUARTZITE
CHERRY BROOK FORMATION
MARLBORO FORMATION
WESTBORO QUARTZITE
RICE FORMATION
WESTFORD
TYNGSBOROUGH
DUNSTABLE
TEWKSBURY
SAFETY PAYS
GRAPHIC SCALES
MILES
FEET
PREPARED FOR CORPS OF ENGINEERS BY ANDERSON-NICHOLS CO. INC. AND GOLDBERG-ZOINO & ASSOC., INC.
REVISION
DATE
DESCRIPTION
BY
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)
BEDROCK GEOLOGY MAP
MERRIMACK BASIN PORTION OF NORTHERN MIDDLESEX AREA COMMISSION
APPROVED
DATE DECEMBER 1973
SCALE
SPEC. NO.
BEDROCK SERIES
SHEET B2



CORPS OF ENGINEERS
U. S ARMY
LOCATION MAP
NORTHERN MIDDLESEX AREA COMMISSION
ATLANTIC OCEAN
M A S S.
PEPPERELL
DUNSTABLE
DRACUT
LOWELL
TEWKSBURY
WESTFORD
CHELMSFORD
BILLERICA
MERRIMACK RIVER
LEGEND FOR FIGURE S2
COARSE GRAINED SOILS
GLACIAL OUTWASH: "Clean" SANDS or SANDS and GRAVEL
ALLUVIUM, RIVER TERRACE DEPOSITS: SAND, SILT; often Gravelly and/or Clayey
GLACIAL TILL: Dense, unsorted Silty or Clayey SANDS and GRAVELS with Cobbles and Boulders
FINE GRAINED AND/OR ORGANIC SOILS
GLACIAL LAKE BOTTOM DEPOSITS: SILTS, Clayey SILTS, Silty SANDS, Varved CLAY & SILT
FRESH WATER ORGANICS: PEAT, Sandy or Silty PEAT, "Muck"
BODY OF WATER (Rivers, Lakes, Ponds, etc.)
SAFETY PAYS
GRAPHIC SCALES
MILES
FEET
PREPARED FOR CORPS OF ENGINEERS BY ANDERSON-NICHOLS CO. INC. AND GOLDBERG-ZOINO & ASSOC., INC.
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)
SURFICIAL GEOLOGIC MAP
MERRIMACK BASIN PORTION OF NORTHERN MIDDLESEX AREA COMMISSION
DATE DECEMBER 1973
SURFICIAL SERIES
SHEET S2

CORPS OF ENGINEERS U. S. ARMY



LEGEND

FAVORABLE FOR DEVELOPMENT OF LOW TO MODERATE VOLUMES OF GROUND WATER (SEE TEXT)

FAVORABLE FOR DEVELOPMENT OF MODERATE TO LARGE VOLUMES OF GROUND WATER (SEE TEXT)

*OTHER PATTERNS - UNFAVORABLE FOR DEVELOPMENT OF GROUND WATER SUPPLIES

SAFETY PAYS

GRAPHIC SCALES

MILES

FEET

1000 0 3000 7000

PREPARED FOR CORPS OF ENGINEERS BY
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DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)

GROUND WATER FAVORABILITY MAP

MERRIMACK BASIN PORTION OF
NORTHERN MIDDLESEX AREA COMMISSION

DATE DECEMBER 1973

DRAWING NUMBER
GROUND WATER SERIES
SHEET W2

A large area of highly favorable deposits is shown in the central part of the map because of the implied presence of the joining of at least two major buried river channels, the potential for continuous supply by surface water, and highly permeable alluvium along the river courses. The location of this area follows the suggested trends of buried river channels. Since the highly favorable area is based on extrapolation only, there may be places within the area which have only moderate or even poor ground water potential.

Areas of moderately favorable ground water potential follow the contact line between stratified drift and glacial till for the most part, but some areas of stratified drift do not appear to have potential for long term support of continuous ground water supply (in Pepperell, Dracut, Chelmsford, and Billerica, particularly). These areas are mapped as unfavorable because of this apparent condition, but later investigations might indicate otherwise. Other areas of low favorability are patterned after areas mapped as glacial till on the Surficial Geology Map.

MERRIMACK RIVER BASIN

3. PORTION OF MONTACHUSETT REGIONAL PLANNING COMMISSION

A. LOCATION, TOPOGRAPHY AND DRAINAGE

Northeastern portions of the Merrimack-Montachusett RPA Area are located in Middlesex County. The southern and western parts occur in Worcester County. The area's bounds follow the New Hampshire state line on the north, the Ashburnham, Gardner and Westminster township lines on the west, continue along southern limits of Sterling, Clinton, and Harvard, and follow the eastern edge of Harvard, Groton, and Townsend to New Hampshire.

The report area lies in the upland sector of the New England physiographic province. Elevations and relief, however, vary considerably from east to west. In eastern portions, hilltops occur around elevation 500, relief varies from 200 to 300 feet. Westward, elevations and relief increase significantly. West of a line passing through Fitchburg, Leominster, and Sterling the crests of hills commonly exceed elevation 1000, and the relief is generally in the order of 400 to 600 feet. Fenneman (1938, p. 358) described the upland section of the New England province:

> ". . . . an upraised peneplain bearing occasional monadnocks and disected by narrow valleys."

Watatic Mountain, a monadnock in Ashburnham, rises to an elevation of somewhat more than 1800 feet, nearly 1000 feet higher than the plateau level around it.

The area is generally well drained. Most of the runoff reaches the Nashua River, and through it, the Merrimack. Parts of Clinton, Harvard, Ayer and the Groton occur in the Assabet basin; this river flows northeastward, joins the Sudbury and becomes the Concord which in turn reaches the Merrimack in Lowell. Extreme western portions of the report area are drained by the Millers and Chicopee Rivers, both of which flow westward and ultimately empty into the Connecticut River.

B. BEDROCK GEOLOGY

The bedrock units in the Merrimack-Montachusett RPA Area occur as more or less alternating bands of igneous and metamorphic types. These outcrop belts cross into New Hampshire trending in a northeast-southwest direction.

Various geologists who have supplied publications and information on the bedrock geology of the area include Emerson (1917) and Fahlquist and Berkey (1935). Studies on adjoining and/or nearby locations by Hansen (1956) and Billings (1956) were also used in preparing this report. The viewpoints of these geologists, however, are divergent so far as they are concerned with the age and structural relationships of rock units in the area.

By any standards the age/structural relations in central Massachusetts are complex. Emerson (1917) mapped and described a variety of meta-sedimentary units in the area including the Oakdale Quartzite, Paxton Quartz Schist, Worcester Phyllite, Brimfield Schist and Boylston Schist; igneous rocks included were the Fitchburg and Ayer Granites. He indicated that the metamorphics were the oldest rocks in the area, having been intruded later by the granites. Billings (1956) places the Merrimack group in the Silurian; considers the Ayer Granite (Granodiorite) and Fitchburg Granites to be younger; and the Worcester Phyllite and Brimfield Schist to be the youngest (Pennsylvanian).

Nevertheless all workers were in agreement on certain generalized aspects of the structural geology of the region. These include:

1. The structural trend is predominately northeastward; outcrop belts of the formations and the strike of their foliation tend in this direction.

2. The meta-sedimentary rocks in the region have been warped into broad anticlinal and synclinal structures; igneous cores of the anticlines are often exposed.

3. Faulting of major dimensions is suspected and expected, but to date has only been verified in a few areas. Several faults indicated by Emerson are shown on the accompanying map (B3).

METAMORPHIC ROCKS

Merrimack Group - Oakdale Quartzite

The Oakdale Quartzite occupies major portions of the Merrimack-Montachusett RPA Area. Its general characteristics have been described elsewhere in this report (Upper Middlesex RPA). A portion near the north-east corner of the study area has been mapped as Emerson's Gneisses and Schists of undetermined age; this area was mapped with the Merrimack group by Billings.

Paxton Quartz Schist

Emerson's Paxton Quartz Schist has been described on page 33. Small areas near Ashburnham and southward have been described as Hubbardston Granite with inclusions of Paxton Quartz Schist. Emerson (1917, p. 234) describes this special case as:

" The flat thin flags of the fissile Paxton quartz schist, consisting only of quartz grains with disseminated biotite scales, persist with little change. Thin contorted layers of the schist from an inch to a foot thick are wholly isolated in the granite, and in places several such bands. separated several feet from each other, retain a common dip and strike. When the last filaments of the schist disappear in the granite they make little change in its chemical constitution."

Worcester Formation - Harvard Conglomerate

This rock represents a basal unit to the Worcester Formation. It is exposed over small areas, one of which is located near the center of Harvard. The following description is by Hansen (1956, p. 20-21).

" The Harvard conglomerate lentil consists of pebbles of several rock types and various sizes in a matrix that is predominantly bluish argillite. The matrix also includes slate, phyllite, chlorite schist, and gritty quartzite. Most of the pebbles are quartzites of various shades of pale green, violet, gray and blue gray. According to Jahns (oral communication, 1949) these quartzites are lithologically the same as quartzite beds in the Merrimack quartzite of the Lowell area. Other pebbles are composed of slate, phyllite, chlorite schist, and milky quartz. Some of the pebbles exceed 4 inches in length, but most of them are much smaller. The pebbles range from sharply angular to well rounded. Most of them are somewhat tabular, and these commonly lie with their flat surfaces approximately parallel to the bedding planes."

Worcester Formation - Worcester Phyllite

The phyllite facies of the Worcester Formation occupies large portions of this report area. It outcrops in a broad band north of the Wachusetts Reservoir to the New Hampshire line (or beyond). The characteristics of this unit are described elsewhere (Northern Middlesex RPA Area).

Worcester Formation - Brimfield Schist

The correlations and characteristics of the "typical" Brimfield Schist have been described earlier (p. 34). However, Emerson maps extensive atypical areas of Brimfield Schist which he described as Hubbardston Granite with inclusions of Brimfield Schist. Emerson's (1917, p. 234-235) description follows:

> ". . . Over the areas formerly covered by this schist many contorted sheets and thin filaments appear. The abundance of iron, biotite, garnet, fibrolite, and graphite in these schists all enable their influence upon the granite to be traced long after their schistosity has wholly disappeared in the massive and highly feldspathic rock. The granite in its purest form is white and almost wholly free from iron; where its ledges rust superficially it is because much of the schist has been incorporated into its mass, and the pyrite of the schist is still easily oxidizable in the granite.
>
> If the areas of the granite in which appear the peculiarities of the Brimfield schist above noted--rustiness, content of graphite, fibrolite, and biotite-- and the areas containing fragments of the Paxton quartz schist are separately indicated on the map, it is seen that the boundaries between the Brimfield and the Paxton on the east of the granite area are continuous across the granite and join the corresponding boundaries on the other side, so that all the granite areas could be mapped as schist areas also and assigned to the different schists which I have no doubt formerly mantled them"

Fahlquist and Berkey (1935, p. 19) in describing the Brimfield Schist relate it to the Fitchburg Granite. They state elsewhere in their writings that the Hubbardston granite is a variety of the Fitchburg granite.

> " Certain varieties show complete recrystallation of the constituents and an intense foliation. Numerous large and small bodies of pegmatite and granite are present occurring both with sharply defined outlines and with transitional zones grading from one rock type into the other. These granite masses resemble in every detail the Fitchburg granite."

Billings (1956, p. 27) maps the New Hampshire extension of this area with the Littleton Formation and in his structural group - the Merrimack syclinorium:

> ". . . The fourth and by far the largest area occupies the Merrimack synclinorium. On the structure map accompanying the geological map, this synclinorium is separated from the Bronson Hill anticline on the northwest by a heavy line and, similarly, is separated from the Fitchburg pluton on the southeast by another heavy line. Along the Massachusetts boundary this band of the Littleton formation is 22 miles wide."

Billings assigns the Littleton Formation to the Devonian age, widely separating it from the Carboniferous age meta-sediments of the Worcester Formation.

Nashoba Formation

The Nashoba Formation of Hansen (mapped by Emerson as unassigned gneisses and schists; by Billings as "Bolton" Gneiss) has been described on p. 34-35). In the report area it underlies the southeast corner of Harvard.

IGNEOUS ROCKS

Fitchburg Granite - Hubbardston Granite

Fitchburg Granite is reported to underlie a large central portion of the Merrimack-Montachusett RPA Area. Emerson (1917, p. 232) considered the Fitchburg granite to be one of the youngest units, intrusive into all the meta-sedimentary rocks in the area. He described it as follows:

> " The typical rock of the core in the large quarries on Rollstone Hill in Fitchburg, Mass., and in Mason, N.H., is a fresh light-colored medium-grained muscovite-biotite-microcline granite. It is massive and uncrushed. It contains large primary plates of muscovite, many of them intergrown with a later biotite."

Fahlquist and Berkey (1935, p. 28-33) correlated the Fitchburg and Hubbardston Granite and presented some plausible explanations for its structural relations to other formations in the region. Billings describes it as the Fitchburg pluton, questionably relating it to the New Hampshire plutonic series of Devonian age (Acadian revolution). This would make it younger than many of the meta-sediments in the report area (Littleton Formation = Hubbardston Granite with inclusions of Brimfield Schist; Merrimack Group = Oakdale Quartzite and unassigned gneisses and schists), but older than others (Worcester Formation = Harvard Conglomerate and Worcester Phyllite and Brimfield Schist).

Ayer Granite

The Ayer Granite occurs in Groton, Ayer and Harvard. It has been described on p. 21-22.

Pegmatite Bodies

Emerson and others mapped a number of small bodies of pegmatite and/or gabbro without assigning them to a specific unit or age. These may be seen on the included maps (B3, B4 & B5).

A generalized description such as "coarse grained rocks of igneous origin" may be offered, but each occurrence is likely to differ significantly and should be described separately.

C. SURFICIAL GEOLOGY

Unconsolidated deposits in this region are generally thinner and less extensive than the RPA Areas discussed earlier. Much of the country is hilly, the steep slopes and summits often showing bedrock outcrops or, where covered, shallow glacial drift. However in eastern portions of the area, especially near the present day Nashua and North Nashua Rivers, large quantities of sand and gravel occur. These deposits are related to glacial Lake Nashua, an extinct lake that occupied lowland areas from the Wachusett Reservoir to New Hampshire.

Glacial Lake Nashua has been long known and extensively studied. Therefore more information is available for this area than others within the Merrimack Basin. The information which was used included: U.S. Geological Survey Surficial Geology Quadrangle Maps (Jahns, 1953; Koteff, 1966; Koteff and Volckmann, 1973), U.S. Geological Survey Bulletins by Alden (1924), and Hansen (1956); State Publications (Fahlquist and Berkey, 1935) and the U.S. Dept. of Agriculture Soil Surveys of Middlesex and Worcester Counties.

In addition to the occurrence of stratified and unstratified glacial drift, the unconsolidated materials described in this area include wind-blown dune deposits, river terrace and alluvial deposits, and fresh water swamp deposits.

Bedrock Surface

The deepest bedrock surfaces in the area are undoubtedly the preglacial stream courses eroded during the Tertiary. One such channel is described by Alden (1924, p. 24-25)

> " The records of test borings to determine the location of the north dike of Wachusett Reservoir, as shown by Crosby, indicated that beneath the pitted sand plains which occupy the broad valley west and southwest of Clinton is a buried rock gorge, evidently an ancient channel of Nashua River. Crosby writes:

. . . .

The lowest elevation (above sea level) of the bedrock surface determined by the borings is 96.5 feet on the center line of the main cut-off, nearly 200 feet west of Coachlace Pond. Since it is improbable that this boring, which has a depth of 272.5 feet, is located over the very lowest point in this profile of the valley, and especially since it failed to reach bedrock, we may fairly assume that the minimum elevation of the bottom of the gorge on this line is at least as low as 95 feet, and probably as low as 90 feet.

That the Nashua River in the narrow gorge at Clinton is out of the course it followed prior to the deposition of the glacial drift is indicated by the topographic relations and by the fact that it flows over a granite ledge at the Chestnut Street Bridge, although at the site of the Wachusett Dam, half a mile farther upstream, borings show that the bottom of the narrow gorge lies 60 to 70 feet below the present bed of the stream. Crosby found that the buried gorge beneath the dam had been cut by a southward-flowing stream along the contact of the westward-dipping granite and phyllite, with a precipitous and even overhanging wall of granite on the west. This gorge was doubtless tributary to the channel now buried beneath Coachlace Pond.

. . . . . .

The presence of the deeply buried channel west of Clinton, with its bottom less than 100 feet above sea level, at so great a distance from the sea-- nearly 80 miles measured along the present courses of the Nashua and the Merrimack-- naturally indicates a further extension of the ancient gorge, even though there are no borings in the Nashua Valley north of Clinton by which its location could be determined."

Alden cites other examples of ancient stream courses, as does Jahns in the Ayer Quadrangle. According to Emerson (1917, p. 16) much of the erosion responsible for the pre-glacial topography is related to the type and distribution of rock units in the area.

.... The central upland, or Worcester County plateau is made up of alternate broad bands of Carboniferous granite and narrower bands of folded schists, repeating in part the structure and lithology of the western upland. The northern part of the westernmost range of granite is rather resistant and forms monadnocks like Mount Grace, but its southern part has been deeply eroded in the Wilbraham Valley. The

> granite belt next east is made up of less resistant rock and forms the Monson Valley and the broad, relatively low strip that stretches from Orange to Palmer. The third granite belt is more resistant again and forms such monadnocks as Wachusett and Asnebumskit. Just east of it the weak Worcester phyllite is worn down in the low Nashua Valley."

Glacial Till

Glacial till of one form or another crops out in more than 60 percent of the Merrimack-Montachusett RPA Area. In western portions of the area the occurrence of till together with bedrock exposures comprises a significantly higher percentage of the total surface area. Most of the deposits here represent ground moraine and ablation moraine, a generally thin and somewhat discontinuous material laid down over and around the bedrock. In this form the till ranges from a compact and blocky variety in deeper zones, to a loose, sandy and friable type where shallow and/or near the surface.

Till exposures in eastern sectors of the RPA Area are less numerous. Thicker deposits in the form of drumlins, however, are not uncommon. Presumably the materials comprising these landforms are of the more clayey and compact older till. Alden (1924, plate 13) presents a map of Massachusetts showing the distribution of drumlins in the state. His map shows groups or bands of drumlins in Lunenburg, Ayer and Groton. Jahns (1953) in his work on the Ayer Quadrangle, describes the latter groups:

> "... Two northeast trending belts of drumlins, best developed southeast of Ayer and east and south of Groton, occur chiefly along the southeastern margins of lowland areas underlain by platy quartzite and quartzitic schist. These drumlins, about 50 in number, consist of the older variety of till described above, but are locally veneered by the looser and less compact younger variety. Most of these hills are 1500 to 3000 feet long, and rise to heights as much as 200 feet above the surrounding country. Their long axes trend south to south-southeast, which is approximately parallel to the known direction of the last ice advance."

Drumlins and/or thick deposits of glacial till elsewhere in the report area are either widely scattered or lie hidden below granular soils and swamp deposits.

Outwash and Ice Contact Deposits

Significant amounts of "clean" stratified sands and sands with gravel occur in the report area. Many of these are associated with what was once a large glacial lake- Lake Nashua. A general explanation for the forming of a glacial lake is provided by Alden (1924, p. 60):

> " In the valleys draining northward or northeastward, the retreat of the ice front as the glacier melted freed the southern parts of the basins from ice while yet the old outlets were blocked, thus causing the formation of temporary lakes at the glacial front, and in these lakes were formed glacio-lacustrine deposits. When the basins were wholly freed of ice the lakes were drained, and the deposits were thus exposed to erosion by the streams. The most notable of these temporary lakes in the Quinsigamond quadrangle were those occupying the Nashua and Assabet river basins, which have, for convenience, been designated glacial Lake Nashua and glacial Lake Assabet."

Lake Nashua during its existence included several stages or levels, each of which covered somewhat different areas and released glacial meltwaters via different outlets. The sequence and correlation of the deposits which accumulated during the various stages and the locations of the outlets for each have been a subject of study for some 75 years. We will not attempt to reconstruct the detailed history of the lake here. Instead, the reader is referred to the work of Crosby (1899), Alden (1924), Jahns (1953), Hansen (1956), and Koteff and Volckmann (1973), whose works describe various aspects of Lake Nashua's location and deposits.

At one time or another during its existence, the glacial lake covered portions of Clinton, Lancaster, Harvard, Shirley, Ayer, Groton and Pepperell in the report area, as well as points to the north and south. It was located in what may be roughly described as the present valley of the Nashua River. Older, high level deposits associated with the ancient lake are found toward the south. As the ice north of the lake receded, lower level outlets were uncovered, the lake's level dropped, and materials deposited within its limits accumulated to successively lower elevations.

A large variety of deposits are related to Lake Nashua. Some were deposited in contact with the ice fronts marking the northern shore of the lake at various times. Others were laid down beneath the more-or-less quiet open waters. Still others accumulated at and within the various outlet channels opened during the lake's history. Thus the types of deposit may be classified as ice contact, outwash, lake bottom, channel fillings and others, most of which may be conveniently categorized as glacio-lacustrine deposits. In keeping with their mode of deposition, the materials which accumulated also differ: sands, gravels, silts, clays and combinations of all four could be expected. For the most part these deposits will show the evidence of water-borne transport, i.e. particle rounding, sorting, and stratification. Jahns (1953) describes some of the relationships seen in the Ayer quadrangle:

> " Outwash was deposited in the relatively quiet waters of this lake to form deltas, such as the broad, sandy plain northwest of Ayer, and the more gravelly plain immediately southeast of Hell Pond. Many of these deltas were built by meltwaters that followed circuitous courses through irregular, broken masses of ice, and hence are traceable shoreward into outwash plains, kame terraces or other ice-contact forms. This transition from open-water deposits into ice-contact deposits is well shown west of the Nashua River from Fort Devens northward to West Groton.
>
> The topset beds of the deltas typically consist of nearly horizontally bedded gravel and sand, whereas the inclined foreset beds are distinctly fine grained. Where not modified by post-lake erosion, the outer slopes of the deltas vary with the coarseness of the foreset material; they also flatten in a lakeward direction, where the underlying sediments grade into typical lake-bottom accumulations of silt and clay."

The thickness of the Nashua related deposits is extremely variable. Locally they are thin, as shallow, higher level terraces perched against glacial till. More often they are thicker, 30 to 50 feet and more. In a few areas they become very thick such as in the gorge-like valley just north of the Wachusetts Reservoir cited earlier (p. 47-48).

Unconsolidated deposits of "clean" granular materials other than those associated with glacial Lake Nashua exist elsewhere in the Merrimack-Montachusett RPA Area. Some of these are undoubtedly related to temporary glacial lakes such as Lake Leominster northeast of Clinton, or Assabet which existed southeast of the report area.

Much of the mapping done in the northern and western regions was completed using USDA Soils Map data. Such information does not define specific depositional sequences or correlations. Those indicated as Hinckley or Merrimack series soils have been included with Outwash and Ice-Contact deposits.

Lake Bottom Deposits

In a general way lake bottom deposits could occur anyplace once occupied by Lake Nashua or the other glacial lakes in the area. They are mapped only where known (see Figure S3). Their accumulation below the relatively quiet waters of Lake Nashua has already been cited. To this explanation, Jahns (1953) adds:

> " Most of the bottom deposits are varved clays, which reflect both seasonal and year-to-year changes in sedimentation and provide a key to the chronology of glacial retreat in the region.
>
> Varved clay underlies several low terraces southwest of Hell Pond, where it evidently was deposited around longlasting masses of ice. It is capped conformably by 15 to 25 feet or more of fine-grained, well-bedded sand, and in places is also covered with younger dune sand. Thin accumulations of varved clay that contain pebbles, some larger rock fragments, and local masses of till are present east of West Groton, and also underlie the low, broad fairgrounds plain on the east side of the Nashua River."

Koteff (1966, p. 2) in describing materials he mapped as lake bottom deposits in the Clinton Quadrangle, states:

> " Lake bottom deposits are shown on the map only for Boylston stage of glacial Lake Nashua. These deposits are chiefly fine sand and silt, although some gravelly sand occurs at the north side of Greenhalge Point in Wachusett Reservoir. Most other lake-bottom deposits are buried by delta deposits. The only other exposed or known lake-bottom sediments are associated with deposits of the Ayer stage. Alden (1924, p. 70-71) found more than 14 feet of clay beneath 10 to 12 feet of sand and fine gravel about half a mile west of Still River Station in Harvard, and Alden (1910) found clay about three-fourths of a mile east of North Village in Lancaster. These exposures are now slumped and very poorly exposed, but a few auger holes drilled in the vicinity penetrated silt and some clay at depths of 5 feet or more. Clay and silt occur near or at the surface of Ayer stage deposits just east of Whittenmore Hill in Lancaster. Other lake-bottom deposits of the Ayer or Groton stages may be present beneath the alluvium and swamp deposits in the Nashua River valley."

Note that both geologists call attention to the presence of granular soils overlying the finer grained lake bottom deposits.

Dune Sands

Small occurrences of wind-blown dune sands have been mapped at various places along the Nashua River. These deposits are most probably related to glacial Lake Nashua, as pointed out by Jahns (1953);

> " Many sand dunes are scattered along the east side of the Nashua River Valley. These probably were derived from the nearly lake-bottom plain soon after drainage of the lake, and hence before sufficient vegetation could grow to stabilize the loose, fine-grained sediment. Some of the dunes occur on the old lake bottom itself, but others lie high on adjacent till-mantled hills. Several of the dunes northwest of Groton and southwest of Groton School show evidence of recent migration, but the distances moved appear to be no greater than a few tens of feet."

Alluvium and River Terrace Deposits

According to Koteff (1966, p. 4), a period of river terracing occurred along the Nashua after disappearance of the glacial lake and before establishment of the river's modern-day flood plain. He describes the deposits as follows:

> " River-terrace deposits of sand, silt, and some gravel occur along the Nashua and North Nashua Rivers and North Brook. These deposits generally are finer grained than the adjacent, higher, glacial lake and glacial stream deposits from which they are chiefly derived."

The flood plains of the Nashua River and its tributaries are underlain by recent alluvium. Northeast of the Wachusett Reservoir, in Lancaster, Groton and Pepperell, the flood plain is nearly one mile wide and shows abandoned meanders and oxbow lakes. The poorly sorted deposit of sand and silt in several such areas is known to be at least fifteen feet thick. These areas are mapped on USDA Soils maps as the Ondawa fine sandy loam.

Fresh Water Swamp Deposits

Swamp deposits are scattered throughout the report area. A number of large swamps occur in Ashburnham, Gardner, Westminster and Lunenburg. Other sizeable areas lie along the Nashua Valley in Lancaster and Shirley. They are sparse in upland till areas and among upper level outwash deposits.

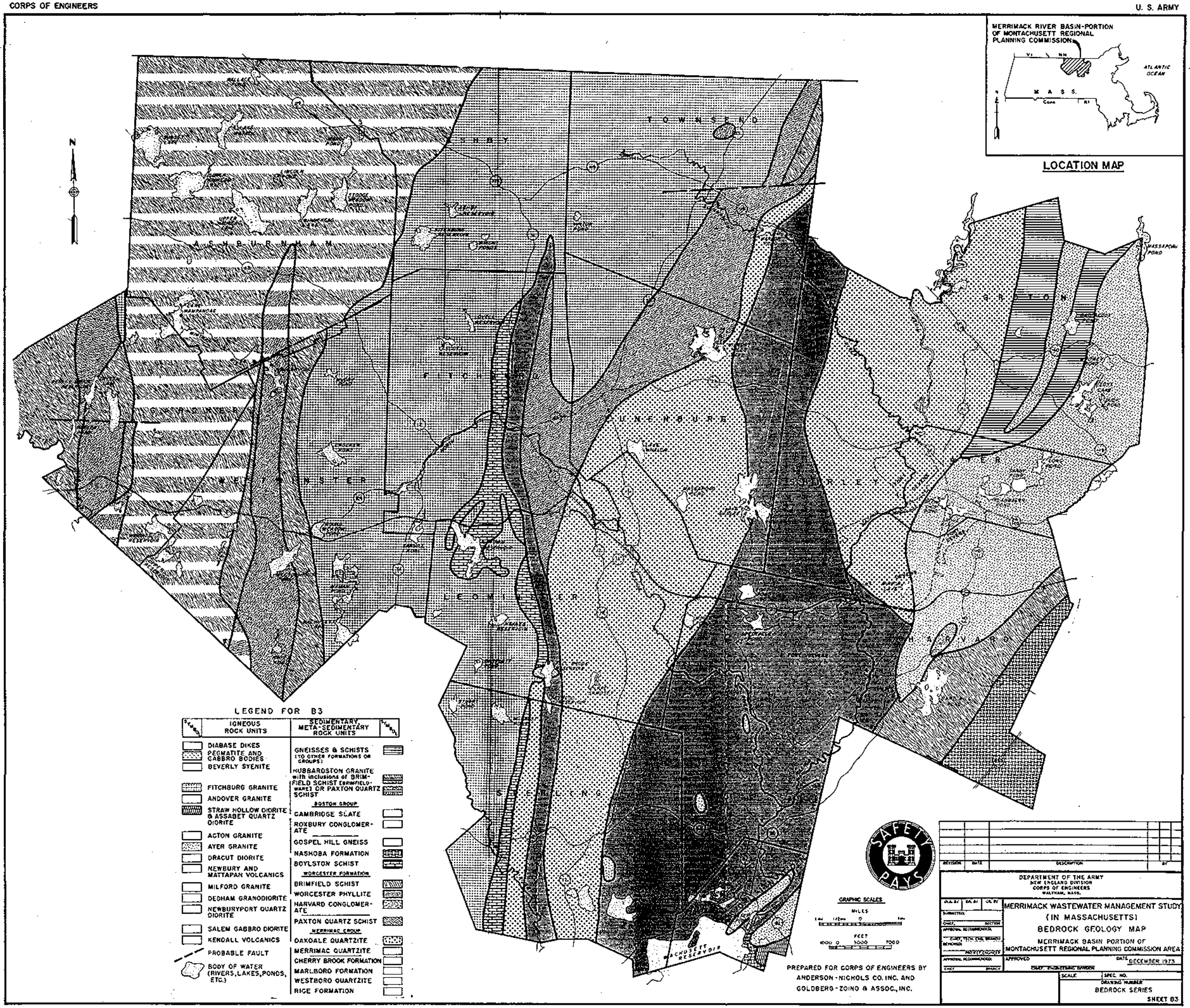
Their occurrence within outwash areas may be of special importance, especially those within the Nashua Valley. There they often mirror the nature of the underlying soils such as hidden lake bottom deposits comprised of silt or clay. They also mask recent alluvium deposits occurring at lower elevations over abandoned meanders and channels.

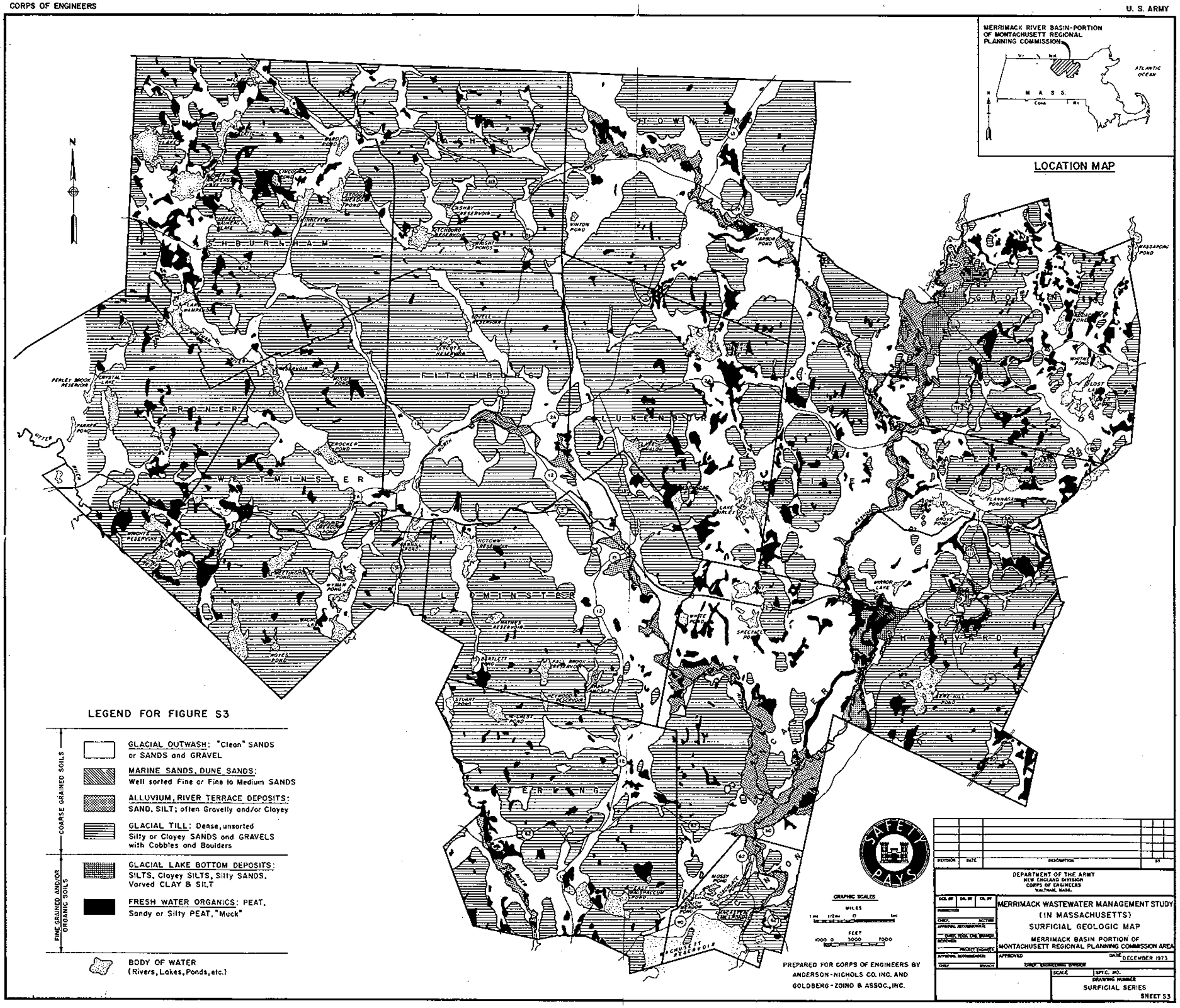
D. GROUND WATER GEOLOGY

The ground water favorability on the portion of Montachusett Regional Planning Commission within the Merrimack River Basin is shown in Figure W3. None of the area is covered by published ground water mapping, but some information is available on the presence of buried river channels in Clinton and an apparent confluence of channels in Ayer. Areas mapped as highly favorable for ground water development are based upon the inferred presence of the buried valleys and on the assumption that the valley fill is highly permeable. The extent and exact location of these highly favorable channels are subjective-- they may extend considerably further than is shown on the map, and the mapping may include areas which actually include lower favorability deposits.

Areas of moderate favorability for ground water development are patterned after the contacts of glacial till deposits and outwash and ice contact deposits. These may include highly favorable areas, particularly along the North Nashua and Squannacook Rivers, and north of the Wachusett Reservoir dam. Significant areas of the outwash/ice contact deposits are excluded from moderate favorability in the western half of the map because of very limited information in the form of well logs or mapping, the knowledge that the surficial deposits tend to be thin in this RPA Area (see Surficial Geology), and a lack of surface indications which would suggest a copious recharging supply (swamps, streams, reservoirs).

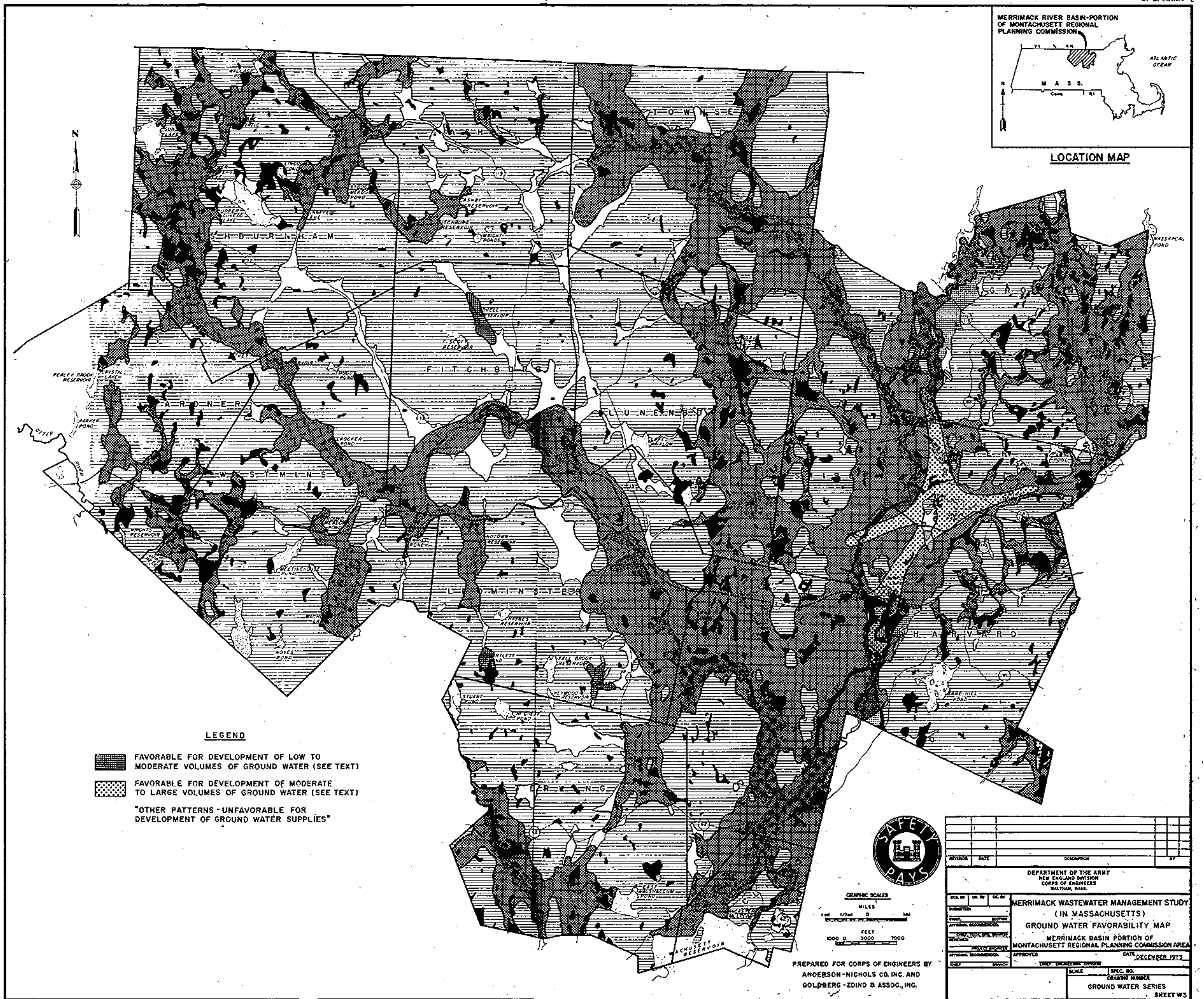
Because of the highly variable deposits associated with glacial Lake Nashua, the favorability trends in the eastern half of the map should be used cautiously. The possibility of extensive deposits of impermeable clays, for instance, could serve both as a layer preventing aquifer recharge or as a layer which could serve as a retaining boundary for water already in the aquifer. The ground water favorability should therefore be used as a guide only, and detailed evaluation should be undertaken for accurate supply determination.


MERRIMACK RIVER BASIN-PORTION OF MONTACHUSETT REGIONAL PLANNING COMMISSION
ATLANTIC OCEAN
M A S S.
LOCATION MAP
TOWNSEND
ASHBY
ASHBURNHAM
FITCHBURG
LUNENBURG
WESTMINSTER
SHIRLEY
LEOMINSTER
HARVARD
STERLING
WACHUSETT RESERVOIR
MASSAPOAG POND
LEGEND FOR B3
IGNEOUS ROCK UNITS
DIABASE DIKES
PEGMATITE AND GABBRO BODIES
BEVERLY SYENITE
FITCHBURG GRANITE
ANDOVER GRANITE
STRAW HOLLOW DIORITE & ASSABET QUARTZ DIORITE
ACTON GRANITE
AYER GRANITE
DRACUT DIORITE
NEWBURY AND MATTAPAN VOLCANICS
MILFORD GRANITE
DEDHAM GRANODIORITE
NEWBURYPORT QUARTZ DIORITE
SALEM GABBRO DIORITE
KENDALL VOLCANICS
PROBABLE FAULT
BODY OF WATER (RIVERS, LAKES, PONDS, ETC.)
SEDIMENTARY, META-SEDIMENTARY ROCK UNITS
GNEISSES & SCHISTS (TO OTHER FORMATIONS OR GROUPS)
HUBBARDSTON GRANITE with inclusions of BRIMFIELD SCHIST (BRIMFIELDWARE) OR PAXTON QUARTZ SCHIST
BOSTON GROUP
CAMBRIDGE SLATE
ROXBURY CONGLOMERATE
GOSPEL HILL GNEISS
NASHOBA FORMATION
BOYLSTON SCHIST
WORCESTER FORMATION
BRIMFIELD SCHIST
WORCESTER PHYLLITE
HARVARD CONGLOMERATE
PAXTON QUARTZ SCHIST
MERRIMAC GROUP
OAKDALE QUARTZITE
MERRIMAC QUARTZITE
CHERRY BROOK FORMATION
MARLBORO FORMATION
WESTBORO QUARTZITE
RICE FORMATION
SAFETY PAYS
GRAPHIC SCALES
MILES
FEET
1000 0 3000 7000
PREPARED FOR CORPS OF ENGINEERS BY
ANDERSON-NICHOLS CO. INC. AND
GOLDBERG-ZOINO & ASSOC., INC.
REVISION
DATE
DESCRIPTION
BY
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)
BEDROCK GEOLOGY MAP
MERRIMACK BASIN PORTION OF
MONTACHUSETT REGIONAL PLANNING COMMISSION AREA
SUBMITTED
APPROVAL RECOMMENDED
APPROVED
CHIEF, ENGINEERING DIVISION
DATE DECEMBER 1973
SCALE
SPEC. NO.
DRAWING NUMBER
BEDROCK SERIES
SHEET B3


MERRIMACK RIVER BASIN-PORTION OF MONTACHUSETT REGIONAL PLANNING COMMISSION
ATLANTIC OCEAN
MASS.
LOCATION MAP
N
ASHBURNHAM
TOWNSEND
FITCHBURG
LUNENBURG
GARDNER
WESTMINSTER
LEOMINSTER
SHIRLEY
GROTON
HARVARD
LANCASTER
STERLING
CLINTON
LEGEND FOR FIGURE S3
COARSE GRAINED SOILS
GLACIAL OUTWASH: "Clean" SANDS or SANDS and GRAVEL
MARINE SANDS, DUNE SANDS: Well sorted Fine or Fine to Medium SANDS
ALLUVIUM, RIVER TERRACE DEPOSITS: SAND, SILT; often Gravelly and/or Clayey
GLACIAL TILL: Dense, unsorted Silty or Clayey SANDS and GRAVELS with Cobbles and Boulders
FINE GRAINED AND/OR ORGANIC SOILS
GLACIAL LAKE BOTTOM DEPOSITS: SILTS, Clayey SILTS, Silty SANDS, Varved CLAY & SILT
FRESH WATER ORGANICS: PEAT, Sandy or Silty PEAT, "Muck"
BODY OF WATER (Rivers, Lakes, Ponds, etc.)
SAFETY PAYS
GRAPHIC SCALES
MILES
FEET
PREPARED FOR CORPS OF ENGINEERS BY ANDERSON-NICHOLS CO. INC. AND GOLDBERG-ZOINO & ASSOC., INC.
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)
SURFICIAL GEOLOGIC MAP
MERRIMACK BASIN PORTION OF MONTACHUSETT REGIONAL PLANNING COMMISSION AREA
APPROVED
DATE DECEMBER 1973
SCALE
SPEC. NO.
DRAWING NUMBER
SURFICIAL SERIES
SHEET S3

CORPS OF ENGINEERS

U. S. ARMY



4. PORTION OF CENTRAL MASSACHUSETTS REGIONAL PLANNING COMMISSION

A. LOCATION, TOPOGRAPHY AND DRAINAGE

The Merrimack River Basin portion of the Central Massachusetts RPA Area is situated in Worcester County. It includes the townships of Princeton, Rutland, Paxton, Holden, West Boylston, Boylston, Shrewsbury, Westborough, Northborough and Berlin. In many respects this area is like the Merrimack-Montachusett RPA just described. Its physiographic setting, bedrock and surficial geologic units as well as general ground water patterns are similar.

The physiographic setting is the same, that being the upland sector of the New England province. Elevations and relief are the greatest in western portions where Mt. Wachusett in Princeton rises to elevation 2000-- more than 1700 feet above the lowest elevations in the eastern portion. Hills east of Wachusetts Reservoir have an average elevation of about 600 feet. Those to the west, especially in Princeton and Rutland, average at nearly twice this number.

The area is drained by the Nashua, Assabet and Sudbury Rivers, all tributary to the Merrimack. Western sectors of Paxton, Rutland, Princeton and Westminster are within the Chicopee Basin, part of the Connecticut River watershed. Southern segments of Paxton, Holden, West Boylston, Boylston, Shrewsbury and Westborough drain to the Blackstone River Basin.

B. BEDROCK GEOLOGY

The alternating outcrop belts of meta-sedimentary and igneous rocks described for the Merrimack-Montachusett RPA Area are more or less continuous into this area. Towards the east a band of meta-sediments outcrops (Nashoba Formation). Proceeding west, the wide band of Ayer granite exposed north of Wachusetts Reservoir is reduced to a narrow strip. Members of the Merrimack group and Worcester Formation are mapped west of the Ayer granite followed by a wide band of Fitchburg Granite and next, in turn, additional meta-sedimentary units.

As described earlier the major structural trends in the region are toward the northeast; outcrop belts of the rock units in this area approximate that pattern. Toward the southeast, however, formations often regarded as among the oldest in the region are exposed. These are the Westboro Quartzite and Marlboro Formation of pre-Cambrian or early Paleozoic Age. The most recent opinions on the age-structural relationships of these units is summarized by Goldsmith and Page (1973, p. 12).

" The older stratified rocks, including some unnamed units, the Westboro Quartzite, and a sequence of mafic metavolcanic rocks formerly mapped as part of the Marlboro Formation are equivalent to the Blackstone Series of Rhode Island. A Late Precambrian age for these units is permissable but not proven. It seems likely there is a major unconformity between these rocks and the overlying sequence of predominantly metavolcanic rocks that includes the Waltham Gneiss, Marlboro Formation, Nashoba Formation, and many unnamed units, all considered to be of pre-Silurian age. Nonconcordant attitudes between the two sequences and local omissions of large segments of the Blackstone Series are more reasonably explained by an unconformity than by postulating fault contacts where no evidence of faults exists, or by assimilation into intrusive rocks."

Other publications used in compiling the bedrock portions of this report and its accompanying map (B4) include works by Emerson (1917), LaForge (1932), Fahlquist and Berkey (1935), Hansen (1956), Billings (1956), and Nelson (1973).

METAMORPHIC ROCKS

Westboro Quartzite

As suggested above, the Westboro quartzite is considered to be one of the oldest rock units in the region. Emerson questionably placed it in the pre-Cambrian, where a consensus of recent opinions have left it. Emerson's (1917, p. 24-25) description follows:

" The Westboro quartzite, the lower of the two Algonkian (?) formations, is a shoreward bed of sugary quartzite, in places actinolitic or biotitic. Across Uxbridge it is stretched into ligniform masses. It occupies nearly the whole town of Hopedale as a pure massive quartzite, and another area of this type extends from Grafton northeastward into Westboro, where much of it contains many minute needles of tremolite. Farther northeast, across Southboro, the lower beds seem to be cut and replaced by the Milford granite. The upper beds are thin, laminated, fine-grained, flinty quartzite. The rock is in many places brecciated and recemented by hematite films."

Marlboro Formation

The Marlboro Formation was described earlier (Merrimack Valley RPA). It is reported to outcrop near Little Chauncy Pond in the eastern part of the report area.

The Oakdale Quartzite, Paxton Quartz Schist, Worcester Phyllite, Boylston Schist and Nashoba Formation, in their "typical" forms have been described elsewhere in this report. So has Emerson's Hubbardston Granite with inclusions of Brimfield Schist and Hubbardston Granite with inclusions of Paxton Quartz Schist. These descriptions are acceptable for the same rock units in this RPA Area with the following possible exception.

Fahlquist and Berkey (1935, p. 15) map Emerson's Hubbardston Granite with inclusions of Brimfield Schist in the extreme western sectors of the area as the Ware Schist. They state:

> "......The rocks of the large area mapped by Emerson as Brimfield Schist in Hubbardston granite have been given new significance by assigning them to and mapping them as a new formation called the Ware Schist. The designation of Hubbardston granite on the preliminary map has been dropped in the interest of simplification. As brought out in this report, the Hubbardston granite is merely a special facies of the Fitchburg granite which has intruded the schists and formed injection schists and gneisses."

They describe the Ware Schist as follows (1935, p. 20):

> " The general appearance of this rock is very similar to that of the Brimfield schist but it is separated from the Brimfield formation by the Paxton formation. The dominant rock type is a dark-brown flaky biotite mica schist containing very little quartz or feldspar but commonly containing garnet, at times in sufficient quantity to be called a garnetiferous biotite schist. Interstratified beds of considerably greater quartz content occur throughout the formation. Some relatively thin layers of feldspathic schist are also present and these sometimes contain green bands similar to those occuring in the Paxton schist. Pegmatite and gneissoid granite make up a considerable portion of the formation. These occur as small and large lens-shaped bodies and masses of irregular shapes with either sharp or transitional contacts."

While writing on their detailed geologic examinations of the Quabbin Aqueduct Tunnel, Fahlquist and Berkey proposed other minor changes for Emerson's map in this region, but they essentially confirmed the approximate locations of his rock units.

IGNEOUS ROCKS

Dedham Granodiorite

The Dedham Granodiorite is reported to outcrop in the southeastern corner of the Merrimack-Central Massachusetts RPA Area. Emerson's description is cited earlier (see p. 19). An additional discussion is presented in an earlier section of this report.

Milford Granite

Outcrops of the Milford Granite are reported from Shrewsbury, Westborough and Northborough. Emerson questionably referred this unit to the Devonian along with the Dedham Granodiorite and others. Emerson's (1917, p. 165-166) description follows:

> " ... The Milford granite occupies a large area extending from Westboro and Southboro, Mass., to Cranston, R.I., and a small area west of the principal one, chiefly in Grafton, Mass. ... Across its broad central area of many square miles the Milford granite is a rather coarse-grained alkalic granite, containing a small quantity of biotite as its dark constituent.
>
> In the granite (or granodiorite) around Upton the bunches of black biotite are larger and somewhat blended, and the rock is darker and distinctly more mafic. The quartz and feldspar are well mixed in a common groundmass, in many places micrographic, and much of the feldspar is an alkalic plagioclase crowded full of large, model-like microlites of epidote."

Emerson (1917, p. 168) also maps a variant of the Milford granite which he has named the Ironstone Quartz Diorite. He describes this rock and its relationship to the main unit as:

> " The Ironstone quartz diorite is the rock that forms the dark hornblendic border zone of the Milford granite. It is named from the village of Ironstone, in the town of Blackstone, where a great ridge of black, heavy rock, well exposed in a long railroad cut, has given a name to the village. This hornblendic border zone can be traced, almost continuously, about the sinuousities of the western margin of the great Milford granite mass, a distance

> of more than 70 miles. It also surrounds the smaller granite stock in Grafton. It ranges in width from a narrow belt to a zone 60 rods wide, but its continuity is broken in only a few places.
>
> The diorite is a dull-black massive rock of fine to medium grain. The coarser portions are more or less gray, mottled with small aggregates of feldspar and quartz, which in places are so abundant as to give the rock the aspect of a dark granite, and this is the prevailing type. Much of the rock is biotitic and the biotite is so plentiful in places that the rock there deserves the name tonalite."

The locale in Grafton to which Emerson refers is that which extends northward into Shrewsbury and Westborough in this report area. Ironstone quartz diorite is mapped with the Milford Granite on the attached bedrock map (B4).

The Ayer Granite, Fitchburg Granite and Hubbardston Granite (=Fitchburg Granite) have been described earlier.

Diabase Dikes

The Diabase dikes are usually too small to be expressed on a map of this scale. However, one area near the Quinapoxet Reservoir was large enough to be shown. Emerson (1917, p. 274) relates most of the dikes to Triassic age eruptive rocks. In describing them from this area, he states that the rock is dull black in color, and:

> ".........The groundmass is exceeding fine-grained and is diabasic and holocrystalline.....Augite occurs in large polysynthetic groups, is of pale amber color, and shows a zonal growth and a rude prismatic cleavage. The white pyroxene characteristic of the Triassic diabase is especially abundant in groups of long, stout, model-like crystals."

B. SURFICIAL GEOLOGY

Unconsolidated materials of five types are mapped in the Merrimack-Central Massachusetts RPA Area: Glacial Till, Outwash and Ice Contact Deposits, Lake Bottom Deposits, Alluvium and River Terrace Deposits, and Fresh Water Swamp Deposits. Of these Glacial Till is the most prevalent, underlying 60 to 70 percent of the area. Outwash, ice contact, and lake bottom deposits attributable to glacial lakes Nashua and Assabet constitute another significant portion of the surficial materials. The remaining areas are occupied by recent swamps and river terrace and alluvium deposits.

Information used to map and describe the various surficial units includes Alden (1924), Fahlquist and Berkey (1935), Hansen (1956), Koteff (1966), Shaw (1969) and the U.S. Dept. of Agriculture Soils Report for Worcester County (1927).

Bedrock Surface

Here, as elesewhere in the Basin, bedrock depths are most often a reflection of the surface topography. In western sectors of the RPA area this is especially true. Rock is exposed as upland ridges and knobs in large portions of Princeton and Rutland. Where hidden by glacial drift the bedrock surface may usually be found within a few tens of feet below ground.

Exceptions to this rule, however, may be noteworthy. For instance, within the deeply buried pre-glacial stream channels described earlier (p. 33). In these rather exceptional cases rock may lie below several hundred feet of unconsolidated drift. Fahlquist and Berkey (1935, p. 10) in reporting on the geology of the Quinapoxet Valley region state:

> " The Quinapoxet Valley for a distance of one mile east of Shaft 2 is covered with modified drift laid down in an early stage of Glacial Lake Nashua. Extending east of this section to the vicinity of Shaft 1 the deposits are of the morainal type, forming an almost continuous cover of variable thickness which made investigation by borings necessary. Such rock outcrops as were located indicated that the present stream does not flow in its original channel. Not only was there uncertainty as to the thickness of the deposits but it was impossible to state where the deepest channel in the rock floor was located. An extensive boring program, therefore, had to be planned to secure the necessary data. The greatest depth of drift penetrated by any of the borings was found to be 114 feet. Within this valley glacial drift is believed to be deposited to a depth of 175 feet more or less. The lowest point reached by borings in the rock floor of the valley was approximately 400 feet above sea level."

That buried stream channels possibly existed between the Quinapoxet River and the Quinsigamond Valley is detailed by Alden (1924, p. 21):

> " The course of the main tributaries of Quinapoxet River from the south slope of Wachusett Mountain suggests an early channel through the gap 820 feet above sea level at the head of Tatnuck Brook and the ancient river valley at Worcester.

Possibly also Stillwater River once went southward to the same valley by way of the gap north of Summit Station. If these inferences are correct these streams must have been diverted to the stream in Quinsigamond Valley through the process of capture, by which the head of one stream cuts back into another stream's valley. As a rule, the pirate stream has a steeper grade or a greater volume or is working on softer rock and is cutting more rapidly than the stream whose waters it captures. That a considerable stream once flowed southward through Quinsigamond Valley is evident from the capacious dimensions of the valley, which is now largely blocked with drift and wholly out of proportion to the streamlets that occupy it."

Glacial Till

As in the other RPA Areas at least two types of glacial till are present. Explanations for their origin are offered in a later section of this report.

Glacial Till (s) in the form of ground moraine are widely distributed in the area. The moraine is most often comprised of a sandy and bouldery variety, but the deposit is rarely more than ten feet thick. Alden (1924, p. 40) describes some general characteristics of the till found in ground moraine in central Massachusetts:

" Besides being compact and difficult of excavation the till may show a rude cleavage parallel to the surface, evidently the result of pressure of overriding ice. Other than this cleavage the typical till shows no definiteness of structure. It is not uncommon, however, for associated sand and gravel to occur in lenses or layers in the midst of the till, or for the material to be semistratified throughout, showing the close association of ice and water action in the process of deposition. In some places bands of associated material are crumpled and kneaded in with the till, as if it had been disturbed by the forward crowding of the ice. Generally the rock fragments in the till are fresh and sound and retain the marks of glacial abrasion. Locally, however, it contains crystalline pebbles that are in a stage of incipient disintegration, so that they crumble beneath the hammer. Throughout most of the area the residuum of preglacial weathering has been entirely removed, but at a few places considerable residual material has been incorporated in the till, and some yet remains undisturbed between the till and the solid rock."

Drumlins and their constituent tills are rather scarce in this RPA Area. Several have been mapped near Northboro center, and a few others are located elsewhere in the eastern regions, but they are generally widely scattered.

<u>Outwash and Ice Contact Deposits</u>

By far the most significant deposits of "clean" sand and/or gravel in this region are associated with extinct glacial lakes. Deposits attributable to Lake Nashua have already been described. They extend southwestward from the Wachusetts Reservoir into Holden where sands and gravels in the Quinapoxet Valley have been correlated with this glacial lake.

East of the reservoir, within the present day Assabet River Valley, another lake once existed. This was glacial Lake Assabet and the deposits referred to its lifespan occur in Westborough, Northborough, and Berlin. They continue northeastward into Hudson. Excerpts from the history of Lake Assabet serve to point out the sequence and mode of deposition in and around the lake, as well as describe the materials which make up its deposits (Alden, 1927, 1. 74-75):

> " The history of glacial Lake Assabet began when the ice front had melted back to the basin of Whitehall Pond, between 2 and 3 miles southwest of Westboro. The water found its first outlet from this basin southwestward through the col to Warren Brook. The first deposit was the sand and gravel underlying the small flat plain that borders the southwest slope of the pond. The swamp south of this plain, marking the position of the open water, is probably underlain by the finer silt.
>
> North of the pond is an extensive deposit of stratified sand and gravel, of which the higher parts are flat and somewhat pitted with kettles. At the north margin it is joined by an esker, . . . which marks the position of the stream discharging from the ice front into the small lake at the time the moraine to the west was being formed. When the ice front stood at the moraine west of Westboro the water escaped southwestward through the col traversed by the railroad. An excavation near the stream exposes fine laminated sand and clayey sand, including berg-dropped boulders.
>
> Continued recession of the ice front opened an outlet to the east, through the valley of Sudbury River. . . Throughout most of that part of the basin . . . sand and gravel are spread so as to form a nearly flat plain of which the general altitude is 300 to 320 feet above sea level. This is higher than that part of the Sudbury Basin east of Westboro and the outlet to the east so

that the deposit may have been completed as fluvial outwash. Northeast of Chauncy Pond, the general altitude of the gravel plain is about 280 to 300 feet above sea level. This corresponds to an outlet eastward by the valley of Stony Brook, now traversed by the Wachusett Aqueduct. On this plain and on erosion remnants of it stand the villages of Northboro and South Berlin and part of West Berlin. Numerous cuts expose the stratified sand and gravel and show that most of the pebbles are less than 4 inches in diameter, but cobblestones and boulders, some very large, are included. In the valley slope at Chapinville fine laminated sand and sandy clay are exposed beneath the gravel. Boulders are generally present on the surface of the plain, which is also pitted more or less by small sags and some larger ice-block depressions. Apparently the deposition took place near the ice front, and some of the abrupt 40 to 50 foot slopes bordering the streams and ponds appear to represent ice contacts. A small terrace with abrupt ice-contact slopes bordering the ridge slope at an altitude of 280 feet 1 mile southwest of Hudson indicates that the lake extended thus far down the valley while yet discharging through the outlet south of Southboro. Some of the sand and gravel in the northern part of the basin may have been brought in by the outflow of Lake Nashua, as there was a difference of about 100 feet in the level of the two lakes when they were in communication through the south-dike outlet. Most of the material, however, probably came directly from the neighboring ice front.

North of Chapinville the gravel of this horizon occurs principally in narrow terraces on both sides of Assabet River and North Brook. At 20 to 60 feet below this level the streams are bordered by a second set of terraces, which decline in altitude from 280 feet above sea level near Berlin to 200 feet near Hudson. These terraces are remnants of a flood plain developed by erosion of the higher valleys, when the melting cleared an outlet by way of Hudson and the col southeastward to Fort Meadow Brook valley and thence to the lower area on the east. This was the beginning of Assabet River."

Other stratified sands and gravels in the area are undoubtedly due to deposition within temporary glacial lakes. According to Shaw (1969) the unconsolidated materials in the Quinsigamond Valley are partially of glaciolacustrine origin.

Stream-laid glacial deposits and ice contact deposits unrelated to the glacial lakes occupy other areas.

Lake Bottom Deposits

Lake bottom deposits shown on the surficial map accompanying this report are limited to small areas near the Wachusetts Reservoir. Their presence elsewhere is likely, probably beneath lowlying swamps and/or alluvial deposits. Alden's description of glacial Lake Assabet cited earlier alluded to silt occurring below a swamp near Whitehall Reservoir. Similar deposits no doubt exist elsewhere in the valleys that once held Lakes Assabet and Nashua.

Alluvium and River Terrace Deposits

River terrace and alluvium deposits are found in eastern portions of the area. Most of them occur along the Assabet River and its tributaries. Terracing and redeposition of unconsolidated glacial materials is evident along certain portions of the Assabet, but these areas and the river's more recent flood plain deposits are less extensive than those seen along the Nashua.

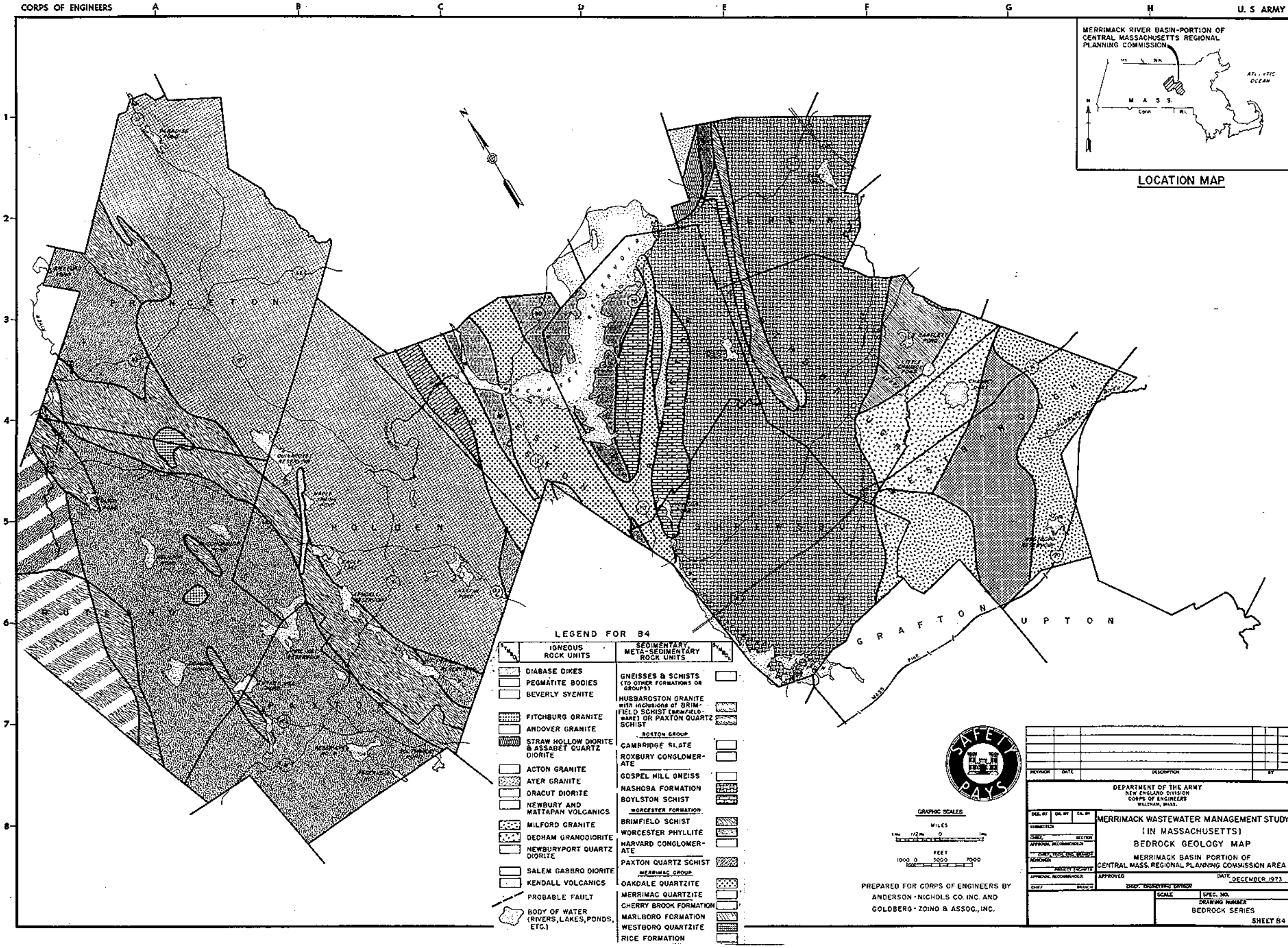
Fresh Water Swamp Deposits

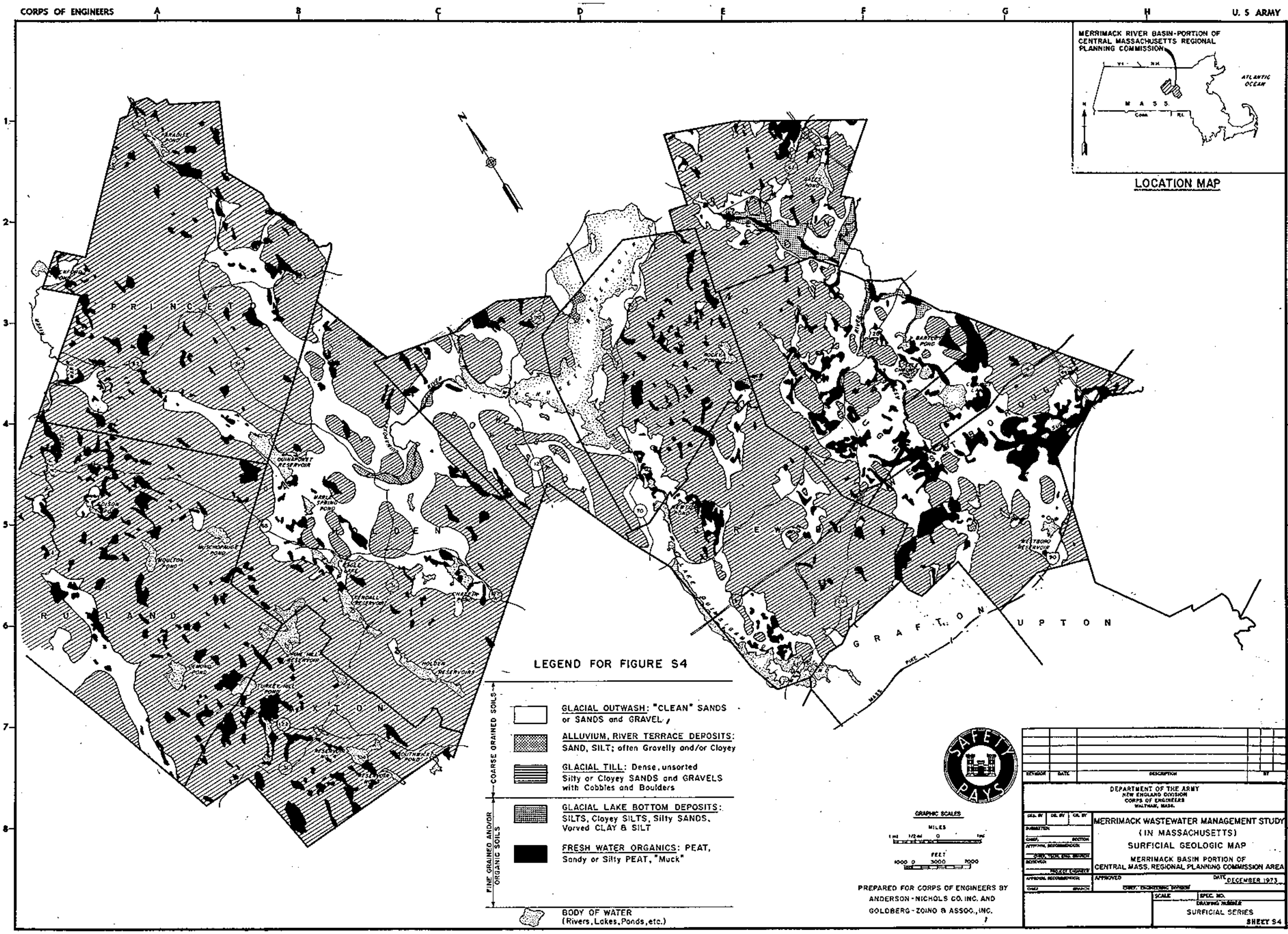
Several large swamps are found in Westborough. Crane Swamp, Cedar Swamp and Hocomonco Swamp each cover several hundred acres. The nature of the soils which may underlie this portion of the old Lake Assabet basin has been cited above. Other smaller swamps also occur here and elsewhere throughout the RPA Area.

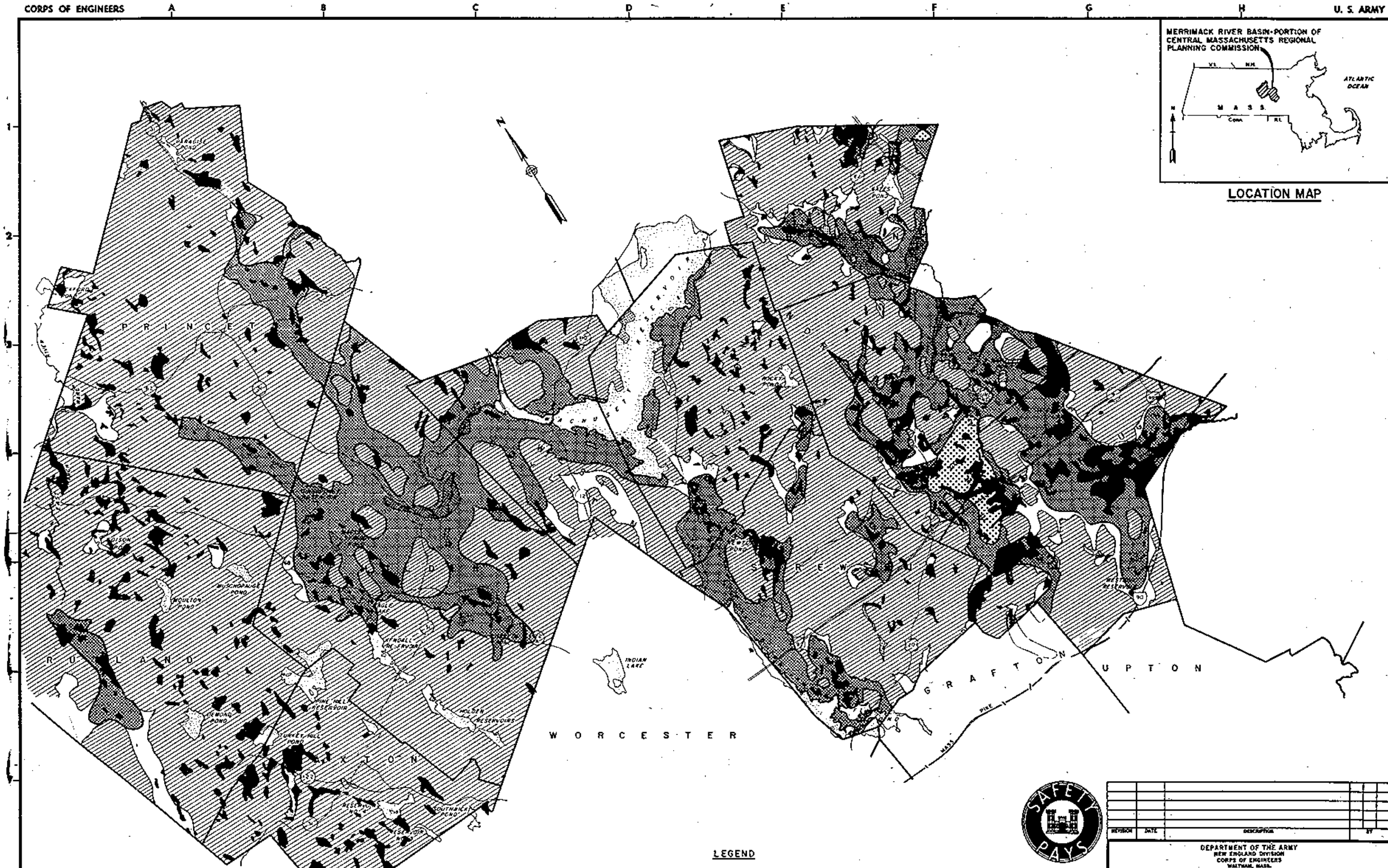
D. GROUNDWATER GEOLOGY

Ground water favorability for the Merrimack River Basin - Portion of Central Massachusetts Regional Planning Commission is shown in Figure W4. Details of the favorability for ground water supply in the northeastern part of map, including the northeast part of the towns of Boylston and Shrewsbury, are direct transfers of the Assabet ground water favorability mapping by the USGS. The remainder of the map area is based upon extrapolation of the relationship between the stratified drift deposits and ground water favorability shown in the northeast part of the map.

One major area of highly favorable ground water conditions is shown along the boundary between Northborough and Westborough, and several smaller areas are mapped to the north of the major area. The remainder of the map shows only intermediate to low favorability, with intermediate favorability in


CORPS OF ENGINEERS
U. S ARMY
MERRIMACK RIVER BASIN-PORTION OF CENTRAL MASSACHUSETTS REGIONAL PLANNING COMMISSION
LOCATION MAP
PRINCETON
HOLDEN
PAXTON
GRAFTON
UPTON
LEGEND FOR B4
IGNEOUS ROCK UNITS
DIABASE DIKES
PEGMATITE BODIES
BEVERLY SYENITE
FITCHBURG GRANITE
ANDOVER GRANITE
STRAW HOLLOW DIORITE & ASSABET QUARTZ DIORITE
ACTON GRANITE
AYER GRANITE
DRACUT DIORITE
NEWBURY AND MATTAPAN VOLCANICS
MILFORD GRANITE
DEDHAM GRANODIORITE
NEWBURYPORT QUARTZ DIORITE
SALEM GABBRO DIORITE
KENDALL VOLCANICS
PROBABLE FAULT
BODY OF WATER (RIVERS, LAKES, PONDS, ETC.)
SEDIMENTARY, META-SEDIMENTARY ROCK UNITS
GNEISSES & SCHISTS (TO OTHER FORMATIONS OR GROUPS)
HUBBARDSTON GRANITE with inclusions of BRIMFIELD SCHIST (BRIMFIELD-WARE) OR PAXTON QUARTZ SCHIST
BOSTON GROUP
CAMBRIDGE SLATE
ROXBURY CONGLOMERATE
GOSPEL HILL GNEISS
NASHOBA FORMATION
BOYLSTON SCHIST
WORCESTER FORMATION
BRIMFIELD SCHIST
WORCESTER PHYLLITE
HARVARD CONGLOMERATE
PAXTON QUARTZ SCHIST
MERRIMAC GROUP
OAKDALE QUARTZITE
MERRIMAC QUARTZITE
CHERRY BROOK FORMATION
MARLBORO FORMATION
WESTBORO QUARTZITE
RICE FORMATION
SAFETY PAYS
GRAPHIC SCALES
MILES
FEET
PREPARED FOR CORPS OF ENGINEERS BY ANDERSON-NICHOLS CO. INC. AND GOLDBERG-ZOINO & ASSOC., INC.
REVISION
DATE
DESCRIPTION
BY
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)
BEDROCK GEOLOGY MAP
MERRIMACK BASIN PORTION OF CENTRAL MASS. REGIONAL PLANNING COMMISSION AREA
APPROVED
DATE DECEMBER 1973
SCALE
SPEC. NO.
DRAWING NUMBER
BEDROCK SERIES
SHEET B4


CORPS OF ENGINEERS
U. S ARMY
MERRIMACK RIVER BASIN-PORTION OF CENTRAL MASSACHUSETTS REGIONAL PLANNING COMMISSION
ATLANTIC OCEAN
M A S S.
LOCATION MAP
PRINCETON
HOLDEN
RUTLAND
PAXTON
SHREWSBURY
WESTBOROUGH
BOYLSTON
GRAFTON
UPTON
LEGEND FOR FIGURE S4
COARSE GRAINED SOILS
GLACIAL OUTWASH: "CLEAN" SANDS or SANDS and GRAVEL
ALLUVIUM, RIVER TERRACE DEPOSITS: SAND, SILT; often Gravelly and/or Cloyey
GLACIAL TILL: Dense, unsorted Silty or Cloyey SANDS and GRAVELS with Cobbles and Boulders
FINE GRAINED AND/OR ORGANIC SOILS
GLACIAL LAKE BOTTOM DEPOSITS: SILTS, Cloyey SILTS, Silty SANDS, Vorved CLAY & SILT
FRESH WATER ORGANICS: PEAT, Sandy or Silty PEAT, "Muck"
BODY OF WATER (Rivers, Lakes, Ponds, etc.)
SAFETY PAYS
GRAPHIC SCALES
MILES
FEET
PREPARED FOR CORPS OF ENGINEERS BY ANDERSON-NICHOLS CO. INC. AND GOLDBERG-ZOINO & ASSOC., INC.
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)
SURFICIAL GEOLOGIC MAP
MERRIMACK BASIN PORTION OF CENTRAL MASS. REGIONAL PLANNING COMMISSION AREA
APPROVED
DATE DECEMBER 1973
SCALE
SPEC. NO.
SURFICIAL SERIES
SHEET S4



LEGEND

FAVORABLE FOR DEVELOPMENT OF LOW TO MODERATE VOLUMES OF GROUND WATER (SEE TEXT)

FAVORABLE FOR DEVELOPMENT OF MODERATE TO LARGE VOLUMES OF GROUND WATER (SEE TEXT)

"OTHER PATTERNS - UNFAVORABLE FOR DEVELOPMENT OF GROUND WATER SUPPLIES"

GRAPHIC SCALES

MILES

FEET

PREPARED FOR CORPS OF ENGINEERS BY
ANDERSON-NICHOLS CO. INC. AND
GOLDBERG-ZOINO & ASSOC., INC.

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)

GROUND WATER FAVORABILITY MAP

MERRIMACK BASIN PORTION OF
CENTRAL MASS. REGIONAL PLANNING COMMISSION AREA

DATE DECEMBER 1973

GROUND WATER SERIES

SHEET W4

areas of stratified drift where obvious sources of ground water are present (along Lake Quinsigamond, Wachusett Reservoir), or where many lakes and swamps are indications of the potential for ground water supply. Small areas of stratified drift in Princeton, West Boylston, and in Rutland do not appear to be well supplied with water on the basis of this survey, and are therefore mapped as having low favorability for ground water development. The remainder of the area is typified by glacial till deposits which are presumed to be unfavorable for development of ground water on the basis of detailed mapping in the northeastern part of the map.

Buried river channels of the pre-glacial Nashua River and its tributaries have been discussed in the "Bedrock Surface" section for this RPA Area. These fall within the moderately favorable map units in the eastern and southern parts of the map. The very deep valleys, which could serve as a very favorable location for ground water prospecting, may be filled with the lake bottom deposits of Glacial Lake Nashua. The lake deposits are highly variable in sizes and sorting, and consequently can be expected to show highly variable permeability. Certain zones within the area mapped as moderately favorable may therefore also be highly favorable, or of very low favorability for the development of ground water supplies.

5. PORTION OF METROPOLITAN AREA PLANNING COUNCIL

A. LOCATION, TOPOGRAPHY, AND DRAINAGE

Within this RPA Area the townships of Bolton and Southborough are in Worcester County; remaining areas are located in Middlesex County. Most of the report area is situated in Seaboard Lowland sectors of the New England physiographic province. Part of it is located in Upland sectors. Fenneman (1938, p. 370) stated that the Seaboard Lowland "is merely the sloping margin of the upland." Emerson (1917, p. 10) describes much of the area as being within "the bordering slope that descends gradually eastward and southeastward from the central uplands (of Worcester County)." The topography in this region would tend to bear them out for the area is neither level nor markedly irregular. Topographic forms in eastern sectors are relatively smooth and rounded with low hills and wide valleys. Those in western sectors are more pronounced, the hills being generally higher with steeper slopes and sharper ridges, and the valleys narrower, appearing more incised into the landscape.

Drainage, via the Assabet, Sudbury, Concord and Shawsheen Rivers, ultimately reaches the Merrimack. The Sudbury and Assabet join to form the Concord River in Concord and from there reach the Merrimack at Lowell; the Shawsheen arrives at Lawrence. Portions of Hopkington, Ashland, Natick, Weston, Lincoln and Lexington are within the Charles River watershed; another part of Lexington together with small pieces of Burlington and Wilmington occurs within the Mystic River Valley. Most of Wilmington is in the Ipswich Basin.

B. BEDROCK GEOLOGY

The bedrock in this area, as described by Emerson and others, is of many and varied types. Here, more than in any other area, the age/structural relations among the rock units are largely unresolved. New information in the Natick and Framingham areas may prove some of the earlier studies and maps invalid (including this one). Unfortunately much of this data is yet unpublished and only those portions available were utilized (including preliminary open-file reports). Obvious discrepancies between more recent data and the other information used are shown on our map by queries. Minimal efforts to reconcile some of the anomalies were made, but these were only for purposes of presenting the available information in a readable form. No attempts to verify the formation contacts and/or limits were made in the field, and no claims are made as to the accuracy of the bedrock map.

Available information used to prepare this report included Emerson (1917), Clapp (1921), LaForge (1932), Billings (1956), Hansen (1956), an open-file map by Jahns, Willard, White et al., Nelson (1973), Volckmann (1973) and

Bell, Nelson, et al.,in Goldsmith and Page (1973). As shown on the included index map (I2), Hansen's work was used in the Hudson and Maynard Quadrangles, and Nelson's map (with minor revisions) was followed in the Natick Quadrangles. Elsewhere most of the mapped rock units and descriptive terminology follow Emerson and/or LaForge.

Quotations follow which may serve to point out the types of new information becoming available in the eastern portions of the Merrimack-Metropolitan RPA Area. Both are from Goldsmith and Page (1973, p. 13):

> A prominent fault and associated cataclistic rock
>
> A zone of cataclastic rock has been mapped along the northeast-trending Bloody Bluff fault in the Framingham and Concord quadrangles by A. E. Nelson. This zone, which is locally 3/4 mile wide, is best developed on what appears to the southeast side of the principal break of the fault. Cataclastic textures include cataclasites, microbreccias, mylonite , mylonite gneiss, and blastomylonite. Although granodiorite is the most common rock type exposed, mafic lavas and tuffs as well as gabbro are also present in lesser amounts.
>
> New data from the Natick Quadrangle
>
> According to A. E. Nelson, a northeast-trending fault in the Natick quadrangle separates Carboniferous rocks on the east from pre-Carboniferous rocks to the west. The younger rocks are all in the chlorite zone of regional metamorphism, and the older rocks range from the lower part of greenschist facies to the almadine amphibolite facies. Two periods of metamorphism are represented in the map area: the first period produces some folding and regional schistosity and metamorphosed the older rock to amphibolite facies; the second period metamorphosed the younger rocks to greenschist facies and apparently retrograded some of the older rocks to greenschist as well. A cleavage, presumably developed during the second period of metamorphism and deformation, is present in the Carboniferous rocks but has not been observed in the older rocks.

As mentioned before we have attempted to include portions of A. E. Nelson's work on the map for this area.

METAMORPHIC ROCKS

Metamorphic rocks, primarily of sedimentary origin are discussed here. Among the oldest of these are the Westboro Quartzite and Marlboro Formations of Emerson, and the Rice Formation and Cherry Brook Formation mapped by Nelson

(1973) in the Natick Quadrangle. Younger rock units include various members of the Worcester and Nashoba Formations and the Boston Group.

Rice Formation

The Rice Formation is mapped in the Natick Quadrangle only. Its distribution there is based on a map by A. E. Nelson (1973). The following description is from Nelson's (1973, p. 8) text description of the Rice Gneiss:

> ". . . medium- to dark-gray equigranular to inequigranular, fine- to medium-grained, variably layered and textured biotite, plagioclase, quartz gneiss; biotite, plagioclase, quartz, microcline gneiss; biotite, plagioclase, quartz, muscovite gneiss; biotite, plagioclase, quartz, microcline, muscovite gneiss, some minor thin beds of quartzite. These rocks are interlayered and locally garnetiferous, contain small pegmatite veins and, in places, irregular silexite and granitic patches and streaks."

This unit has been described as of "Pre-Devonian" age, and is the oldest rock type identified in the Natick quadrangle. Its structural relations to other units in the quadrangle and distribution outside of this area are not available.

Emerson mapped this area with his gneisses and schists of undetermined age.

Westboro Quartzite

The Westboro Quartzite is mapped by Emerson in Southboro and Framingham. Nelson maps additional areas in Natick and Weston which Emerson apparently grouped with his Gneisses and Schists of indeterminate age. However, Emerson (1917, p. 86) described rocks not unlike the Westboro Quartzite in this area as follows:

> ". . . In Natick and the immediately adjacent territory are numerous exposures of a fine-grained, white, somewhat laminated or schistose, highly siliceous rock of puzzling character. It has been regarded by some geologists as a quartzite and by others as an intrusive rhyolite or aplite. As its age is not yet definitely ascertained, it is for the present mapped with the other other gneisses and schists of uncertain age."

Marlboro Formation

The Marlboro Formation occurs throughout the southeastern two-thirds of the report area, primarily as narrow strips trending northeast across the breadth and width of the region. Emerson also mapped them in the northern parts of the Natick quadrangle, whereas Nelson (1973) did not. These areas, according to Nelson, are occupied by the Kendall Volcanics, members of the Cherry Brook Formation, and others.

Gneisses and Schists of Undetermined Age

Waltham Gneiss

Most of the rock units in the Merrimack Basin which Emerson left unassigned have been correlated with formations described by other geologists. An area in Lexington, Burlington and Wilmington remains questionable. On map B5 this zone is unassigned. In his text discussion Emerson (1917, p. 78-89) described the location of this area as a ". . . belt, long sinuous and branching, extends from Sherborn through Waltham and Woburn to North Reading." However, he fails to describe the rocks which occur there.

LaForge (1932) maps part of this area as Waltham Gneiss, a formation which he named and tentatively referred to a pre-Cambrian age. His (LaForge, 1932, p. 16) description follows:

> " The formation occupies much of northern Waltham, southeastern Lexington and Burlington, and northwestern Woburn. It extends northeastward into the Lawrence quadrangle and southwestward into the Framingham and Franklin quadrangles. It is fairly resistant and forms rather rough hills, and its outcrops are abundant.
>
> The formation comprises several varieties of biotite gneiss and hornblende gneiss, some aplitic gneiss, and a few porphyroid gneisses containing conspicuous crystals of feldspar in a matrix that is largely biotite. In some of the coarser-grained biotite gneisses the layering is irregular, and these varieties appear to be of igneous origin and were probably granites and diorites that have been strongly sheared. The aplitic varieties appear to be intrusive into the rest of the complex and may be part of a much you younger intrusive group. . .
>
> . . Besides these varieties there are fine-grained biotite gneisses more siliceous than the other sorts, in which the layering is so regular and so much like stratification as to raise the question whether they are not recrystallized micaceous sandstones.
>
> Although there are local irregularities the foliation of the gneiss has a general northeasterly strike and stands vertically or dips steeply northwestward."

Bell (1948, p. 203) has disputed this assignment and states that these rocks belong to other units (Westboro Quartzite, Marlboro Formation, Woburn Formation, and others).

Cherry Brook Formation

Nelson (1973, p. 6) identified three units in the Natick quadrangle which he assigned to the Cherry Brook Formation. They include a light gray felsic tuff with beds of schist; green-gray, fine to coarse grained amphibolite, and a dark colored fine to medium grained gneiss. These areas are mapped as the Marlboro Formation or Dedham Granodiorite by Emerson (1917) and LaForge (1932 - Figure 2).

Worcester Formation

Three members of the Worcester Formation are represented in The RPA Area. These are the Harvard Conglomerate, Worcester Phyllite and Brimfield Schist. They occur in the westernmost sector only (Bolton and Littleton) and have been described elsewhere in this report.

Nashoba Formation

The Nashoba Formation occupies a large section of the RPA Area. Most of the northwestern half of the region is reportedly underlain by various members of this formation. Emerson (1917) mapped this area as unassigned gneisses and schists, but described them as being the "Bolton" gneiss. Hansen (1956, p. 31-39) named the unit the Nashoba Formation. His description follows:

> " In the Hudson and Maynard quadrangles the Nashoba formation underlies a wider area than all other formations combined. The great width of its outcrop belt undoubtedly is due part to multiple folding, although the details of its complicated structure have not been fully solved. Its thickness may well exceed 5,000 feet.
>
> The formation is composed chiefly of biotite gneiss but contains also biotite schist, numerous interbedded layers of amphibolite schist, hornblende gneiss, quartzite beds that are largely feldspathized, and a few beds of marble. It also contains abundant masses of pegmatite and veins of quartz."

Mapping beyond the Hudson and Maynard quadrangles was based on work by Jahns, Willard, White, et al. (preliminary bedrock map, Lowell-Westford area) and Billings (1956, p. 100).

Gospel Hill Gneiss

The Gospel Hill Gneiss is described by Hansen (1956, p. 37-40):

> " The name Gospel Hill gneiss is suggested for a large mass of granitic rocks of Carboniferous age that Emerson (1917, p. 220)

mapped as a variant of the Andover granite but that is here regarded as a granitized product of the Nashoba and Marlboro formations. Not only is the rock unlike the typical Andover granite of Essex County, but it displays abundant evidence of its metasomatic origin. It is particularly well exposed on the rugged southeast slopes of Gospel Hill in Hudson, the locality from which it was named. It extends from the Concord quadrangle southwestward across the Maynard quadrangle, through the southeast corner of the Hudson quadrangle and into the Marlboro quadrangle. In Concord and Sudbury it is separated from the main mass of the Nashoba formation by the wedge-shaped body of Assabet quartz-diorite. The outcrop belt is narrowest in Sudbury where it is less than half a mile across. To the southwest in the Hudson and Marlboro quadrangle it thickens to a width of more than 2-1/2 miles.

The rock is composed chiefly of microcline, albite, quartz, muscovite, and biotite. In some exposures, however, biotite is scant or lacking. Garnet is a prominent accessory mineral, and some crystals are as much as half an inch across. Apatite is widely distributed as minute rods and prisms.

On exposed surfaces the rock is typically pearly gray to almost white. Fresh surfaces tend to be pinkish or flesh colored. It is of generally uneven grain and of medium to coarse texture. Its foliation, commonly moderate, ranges from vague to strong and is due largely to a subparallel arrangement of wavy, somewhat bent, plates of mica."

Mapping of Hansen's Gospel Hill gneiss unit has been discontinued at the edge of the Maynard quadrangle. On the attached map (B5) this point is shown by a query; for lack of any other information, Emerson's Andover Granite is mapped east and north of there.

Boston Group - Roxbury Conglomerate

The Roxbury Conglomerate underlies portions of the study area in Natick. The age and relationship of this unit to other older rocks to the northwest have already been cited (see p. 67). Nelson's (1973, p. 2) description follows:

" Pale-red to pink-gray coarse cobble conglomerate, cobbles well rounded and variable in size and lithology; matrix is medium grained containing quartz, feldspar, epidote, and chlorite, some small lithic fragments, and reddish-purple clay, massive to poorly bedded; yellowish-gray sandstone that is rarely crossbedded, and purple-gray silty shale or shale intercalated with conglomerate."

The outcrop area mapped by Nelson approximately agrees with those mapped by Emerson and LaForge.

IGNEOUS ROCKS

Kendall Volcanics

The Kendall green volcanic ash occupies a small portion of the Natick quadrangle in Weston. It probably extends northward (into Concord quadrangle), but its distribution there is unknown. Nelson (1973, p. 7) describes it as follows:

" Light-tan to light-gray very fine grained distinctive thinly laminated ash consisting of quartz, feldspar, sericite, and calcite that is interlayered with dark-greenish-gray fine-grained ash containing biotite, plagioclase, quartz, hornblende, epidote, and chlorite, and some discontinuous thin layers of fine-grained light-gray quartzite."

The Kendall volcanics are described as being of pre-Devonian age, and therefore among the oldest igneous rocks in the area.

Dedham Granodiorite

The Dedham Granodiorite underlies considerable portions of the report area. According to Hansen (1956, p. 16) this rock is in part quartz diorite. His explanation and description follow:

" Most of the Dedham granodiorite, as mapped in eastern Massachusetts, is really of granodiorite composition, but several other acid and intermediate varieties are included in the formation. One such variant is the quartz diorite of the Maynard quadrangle. Within this area its outcrops are confined to the town of Sudbury, but judging from widespread glacial boulders the formation apparently extends into adjacent towns. As exposed the rock is a medium-grained medium-light-gray faintly foliated quartz diorite composed chiefly of calcic oligoclase and quartz but containing both hornblende and biotite. . .

. . . The biotite and hornblende are important constituents and together compose as much as 25 percent of the rock. Orthoclase generally is present in minor amounts and in places is sufficiently abundant to give the rock a pinkish hue. Minor accessory minerals are sphene, apatite, and zircon.

Salem Gabbro-Diorite

Hansen maps two areas in the Maynard quadrangle as being underlain by "Salem (?) gabbro-diorite." These areas are within the general outcrop belt of the Dedham Granodiorite, and other workers have mapped it with the granodiorite. They include Emerson (1917) and evidently Nelson (1973), whose studies in the adjoining Natick quadrangle do not continue Hansen's interpretation. On the attached map (B5) the Salem gabbro-diorite units are discontinued at the edge of the Maynard quadrangle.

The Milford Granite, Ayer Granite and Andover Granite occur in various sectors of this RPA Area. Their characteristics and relations to other units in the Basin have been discussed earlier.

Mattapan Volcanics

Nelson (1973) maps rocks in the extreme southeastern corner of the report area as the Mattapan Volcanic Complex of Devonian age. He has described three units of the Mattapan volcanic complex: siliceous volcanic rocks, intermediate volcanic rocks (lavas, breccias, etc.) and laharic deposits. All three are included in the small area which has been mapped as the Mattapan Volcanics (see map B5).

LaForge (in Emerson, p. 200) describes the Mattapan Volcanic Complex as follows:

> " The igneous rocks of the Mattapan complex may be roughly classified as felsites and melphyres. The felsites are prevailingly light-colored and are largely quartzophyric rocks, chiefly dacite, but they include andesite, trachyte, and some granite porphyry. The melaphyres are commonly dark, to a considerable extent amygdaloidal, and comprise chiefly andesite, trachyte, and diorite porphyry but include some basalt."

The unit limits in the report area mapped by Emerson, LaForge and Nelson essentially agree.

Acton Granite

The Acton Granite has been named by Hansen (1956, p. 48-49) from small igneous plutons in Acton, Boxborough, Stow and elsewhere in the Hudson and Maynard quadrangles. His description follows:

> " The Acton granite is a hard and fresh fine-grained moderately foliated rock, light gray to light olive gray on fresh surfaces. On weathered surfaces it is almost white and has a bleached appearance. The rock is composed chiefly of quartz, orthoclase, microcline, and

oligoclase. Mica, including both biotite and muscovite, is the chief accessory mineral and gives the rock its foliated structure. Apatite, zircon, garnet, and a little epidote are minor constituents."

Straw Hollow Diorite/Assabet Quartz Diorite

Isolated named units of diorite are here considered together. The Straw Hollow diorite occurs in Hudson and Marlborough near the western limits of the report area. It also outcrops elsewhere in this region within other RPA Areas. Emerson (1917, p. 219-220) named the unit. His description is included here:

> " The rock of these intrusive masses ranges from gray gneissoid quartz diorite through brown and black traplike rocks to hornblendite. The diorite and quartz diorite ordinarily contain both olive-green biotite and pale secondary hornblende. The rock of some masses also contains diopside, as in the areas near Hudson.
>
> The large mass of diorite and quartz diorite near Clamshell Pond, southeast of Clinton, is generally schistose to gneissic and ranges from amphibolite to quartz-mica diorite. It is irregularly intruded into the Carboniferous schists and in places contains abundant fragments of other rocks."

The Assabet quartz-diorite was named by Hansen (1956, p. 46) from outcrops near the Assabet River in Maynard. The main portion of the rock mass, as described by Hansen, is a tongue-shaped area extending from the town center in Maynard northeastward into the Concord quadrangle. This area has not been mapped by Jahns, Willard, White, et al. (USGS open file) in Concord; their map unit in this region is primarily the Nashoba Formation. Emerson mapped the area as gneisses and schists of undetermined age ("Bolton" Gneiss = Nashoba Formation).

On map B5, a dashed line within the Nashoba Formation is used to show Hansen's limits of the Assabet quartz-diorite unit. His description follows:

> " The rock characteristically is medium grained, medium to dark gray, and slightly to moderately foliated. It is composed chiefly, and in order of abundance, of andesine, hornblende, quartz, and biotite, and contains considerable accessory apatite and some sphene and hematite. The foliation of the rock is due largely to a planar orientation of the hornblende, and in a lesser measure of the biotite, some of which is secondary after hornblende. On weathered surfaces the biotite is altered to a bronze red."

Pegmatite Bodies - Gabbro Bodies

Large individual, unassigned rock units of Pegmatite, gabbro and other coarse-grained igneous rocks have been included on the bedrock map. In this instance, the areas are gabbro. They are located within the Natick quadrangle and represent Nelson's (1973 p. 4) findings.

> " Medium- to dark-gray, fine-grained massive non-foliated rock. Most commonly has subophitic texture; plagioclase, clinopyroxene, and magnetite are principal minerals, less common are biotite, epidote, sericite, and chlorite. Occurs as dikes and small stocks, contacts are sharp and rock has chilled borders near contacts. Has characteristic chocolate-brown-weathering surfaces. Intrudes all pre-Devonian rocks."

C. SURFICIAL GEOLOGY

The surficial deposits in portions of the Merrimack-Metropolitan RPA Area have been described and mapped by many geologists over the past 50 years. Those whose work was used in preparing this report include: Alden (1924), LaForge (1932), Jahns (1953), Hansen (1956), Castle (1959), Chute (1959), Baker (1964), Koteff (1963, 1964, 1966) and Nelson (1972, 1973). In addition, several studies in adjoining areas have been consulted, as well as the U.S. Department of Agriculture Soil Surveys for Worcester and Middlesex Counties.

Most of the unconsolidated deposits in the region are of glacial origin, occurring as either stratified or unstratified drift. Less extensive areas are underlain by river terrace deposits, alluvium and swamp deposits, which have accumulated since withdrawal of the glacial ice. The unstratified drift or till is the most extensive of the unconsolidated materials in the region. It underlies at least half of the area. Stratified drift deposits were most often laid down in temporary glacial lakes that formed in basins near the front of the wasting ice mass. At least four such glacial lakes are known from the report area. Recent stream activities account for the deposition of river terrace and alluvium materials. The accumulation of organic soils found in swamps is also attributable to post-glacial processes.

Bedrock Surface

Several deep, sediment-filled bedrock valleys are known from Eastern Massachusetts. I.B. Crosby (1939, p. 372-383) mapped the locations and conjectured locations of at least four such valleys and their tributaries in this RPA Area. Chute (1959, p. 187-216) described in detail a valley extending from Wilmington southeastward to Boston Harbor. Although most of this route is outside of the report area, its continuation northwestward would be of significance. I.B. Crosby (1939, p. 376) postulated that this may have been the course of the pre-glacial Merrimack River.

" A broad valley continues through the hills of Woburn, and wells in North Woburn, East Woburn and Winchester show that there is a deeply buried valley. It has not yet been proved whether the preglacial. Merrimack Valley continued through the hills and was continuous with the buried valley in Woburn or whether there was a low divide near the Woburn-Wilmington line. If the preglacial Merrimack did not go this way, it probably flowed easterly from Wilmington towards Salem. In any case, we know that there is a continuous valley, now filled with glacial deposits, extending down through Woburn, Winchester, Arlington, Cambridge, Allston, and the South End to Dorchester Bay."

Others have questioned this view, as well as Crosby's alternate easterly route for the ancient Merrimack. Baker (1964, p. 10-13) discusses several opinions on the various areas through which the preglacial drainage system leading to the Assabet River, and LaForge (1932, p. 78-80) describes the general routes of ancient stream channels into the Boston area. References to the preglacial Nashua river system have been cited earlier (p. 47-49).

Glacial Till

Glacial debris is deposited as ground moraines and drumlin hills throughout the area. The drumlins, as mapped by Alden (1924, plate 13), appear to be especially abundant across the southern portions of the area. A broad arc-shaped area in which many drumlins occur begins near Bolton and proceeds eastward through Marlboro, Framingham, Weston and into the Boston area. Another group or drumlin field is seen along the Assabet River in the Stow-Acton region. According to LaForge (1932, p. 54-55) and Hansen (1956, p. 62-63), no relationship exists between the drumlins and the bedrock surface in these areas. Hansen states:

" In the Hudson and Maynard area no obvious relationship exists between the positions of the drumlins and irregularities in the bedrock surface. Drumlins occur to the lee, to the stoss, on the flanks, and on top of bedrock hills. They are found in valleys, on broad plains, and in hilly uplands. They occur singly or as composites--partly joined clusters of two or more."

Outwash and Ice Contact Deposits

Deposits into and associated with at least four extinct glacial lakes account for much of the "clean" sands and gravels found in this area. These were glacial Lakes Assabet, Charles, Sudbury, and Concord. Coarse-grained or granular soils associated with all of them have been mapped as outwash and ice contact deposits. Where discernible, their finer grained materials have been mapped as lake bottom deposits.

Alden's (1924, p. 74-75) description of glacial Lake Assabet has been cited earlier. Most of the deposits associated with this lake exist to the south and west in the Merrimack-Central Massachusetts RPA Area. Hansen (1956, p. 80-81) describes ice contact deposits in Hudson which he attributes to glacial Lake Assabet.

Glacial Lake Charles occurs in parts of Sudbury, Framingham, Wayland, Natick and points south. Goldsmith and Page (1973, p. 16), in summarizing Nelson's work in these areas state:

> " Glacial Lake Charles and Sudbury successively occupied large parts of the Framingham and Natick quadrangles and adjacent areas during the Pleistocene. These lakes were the sites of deposition for most of the extensive stratified sand and gravel deposits that are presently exposed over much of the area. During the life of these lakes, at least within the map area, there were ten principal lake levels or stages, each succeeding stage being lower than the previous one. Lake Charles had five stages and Lake Sudbury, which formed later, also had five stages."

Glacial Lake Sudbury once occupied large areas in Maynard, Sudbury, Concord, Wayland, Framingham and elsewhere, chiefly in the Sudbury River Basin. Koteff (1964, p. 2) describes some of the relationships among the glacial lake deposits, their associated land forms and the materials they may contain in parts of the report area.

> " Glaciolacustrine-glaciofluvial deposits include clay, silt, sand and gravel laid down in or graded to glacial Lakes Sudbury and Concord. In some places the deposits are entirely glaciolacustrine in origin, for example the lake bottom sediments; in other places the deposits are entirely glaciofluvial in origin. . . . Glaciofluvial deposits such as these are included with the glaciolacustrine deposits because of their close association with glacial lakes.....
>
> The glaciolacustrine-glaciofluvial deposits include typical morphological forms constructed in a glacial lake environment, such as kame deltas, which were built in contact with ice on one or more sides. Many of the kame deltas are connected with eskers or ice-channel fillings that acted as feeders to the kame deltas.

Exposures in the kame deltas deposited in glacial Lake Sudbury and the high stage of glacial Lake Concord show as much as 20 feet of topset beds consisting chiefly of fine-, medium-, and coarse-grained sand, and pebble and cobble gravel overlying foreset beds of fine-, medium-, and coarse-grained sand, with scattered pebbles. However, the large gravel pit in the delta in Lexington has exposed chiefly fine- and medium-grained sand, with scattered pebbles."

Deposits associated with glacial Lake Concord occur more or less northeast of those assigned to Lake Sudbury. Koteff (1963, 1964) has described and mapped in detail three stages of sedimentary deposition and three outlets by which the glacial meltwaters exited. A significant amount of the unconsolidated materials found within the limits of Lake Concord are fine-grained lake bottom sediments. They are described below.

Other deposits of sand and/or gravel within the RPA Area are referred to several unnamed glacial lakes by Nelson (1972, 1973). He maps deposits formed in glacial lakes "near Marlboro" and "near Ashland". Coarse-grained (granular) glacial lake deposits, glacial stream deposits, ice contact deposits, outwash deposits, as well as any and all others which may be described as stratified and sorted sands and/or gravels have been mapped together.

Lake Bottom Deposits

Lake bottom deposits referrable to several of the extinct glacial lakes have been mapped by Koteff (Concord Quadrangle, 1964) and Nelson (Natick Quadrangle, 1972; Framingham Quadrangle, 1973). Koteff's description of lake bottom deposits referred to glacial Lake Concord is quite specific.

" The lake-bottom deposits are chiefly fine- and medium-grained sand overlying silt and silty clay. No average thickness for the overlying sand was determined, but many test holes penetrated at least 5 feet without reaching silt or clay. Silty clay also was observed underlying 4 feet of sand about 1000 feet south of Revolutionary Ridge in Concord. Numerous test borings at Hanscom Field penetrated silty clay beds from 0 to 15 feet thick, underlying 2 to 15 feet of sand and overlying 0 to 15 feet of coarse gravel. The lacustrine sediments appear to overlie a discontinuous thin lens of till; in places these sediments lie directly on bedrock. The average thickness of the lacustrine sediments at Hanscom Field appear to be about 25 feet."

Koteff and Nelson (1972) map bottom deposits which they assign to glacial Lake Sudbury. Hansen (1956, p. 77) describes an area in the Sudbury River basin as "composed of lake bottom deposits." This area has been mapped on S5.

Alluvium and River Terrace Deposits

River terrace deposits are described and mapped sparingly in the Merrimack-Metropolitan RPA Area. Here, as elsewhere in the basin, they are partially reworked glacial deposits. In many places geologists question the origin of various stream and/or river terraces, such as Koteff's statement (1964, p. 2):

> " River terrace deposits of sand, silt, and gravel are shown along Stony Brook and a short segment of Hobbs Brook where a fairly well-defined terrace occurs. The composition of the deposits is very similar to that of adjacent glaciofluvial deposits, but it unclear whether the river terrace deposits represent (these) deposits eroded in place, or were laid down by a higher than present stage of Stony and Hobbs Brooks."

Alluvial deposits are more prevalent. They occur along portions of the Assabet, Sudbury, Concord and Shawsheen Rivers, as well as along smaller brooks and streams tributary to these rivers. In general the alluvium occurs within the narrow flood plains of the streams and rivers, where they are relatively thin deposits of silt and sand with minor amounts of gravel and/or organic debris. Locally, however, the alluvial materials may become thicker, including reworked glacial soils and colluvium.

Fresh Water Swamp Deposits

There are many swamps within the report area. This is partially due to the relatively low relief in much of the region, especially in the broad basins which once held the glacial lakes. Swamp formation also depends on the types of underlying soils present, particularly if they happen to occur over impervious lake bottom deposits. The large swamps in the Sudbury and Concord basins are related to these conditions. Hansen (1956, p. 77) describes those in the Sudbury basin:

> " The broad swamps in that portion of the Sudbury basin drained by Cold Brook, Pantry Brook, and Bridge Brook are bounded, at least partly, by steep banks that range in height from a few feet to 10 feet or more. The individual swamps, therefore, are separated by intervening, somewhat higher areas composed of lake-bottom deposits, and the steep banks that separate tham are probably ice-contact slopes."

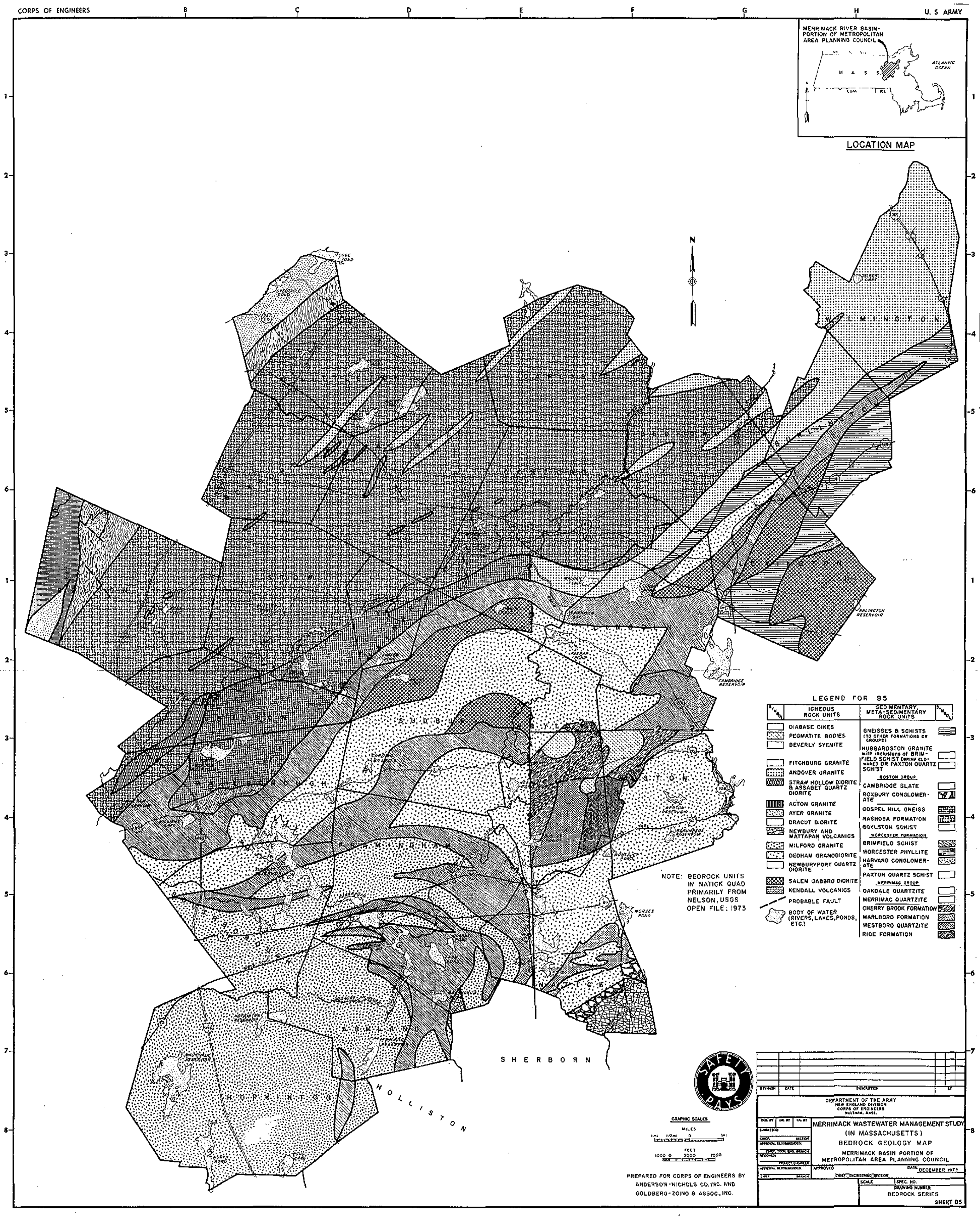
D. GROUND WATER GEOLOGY

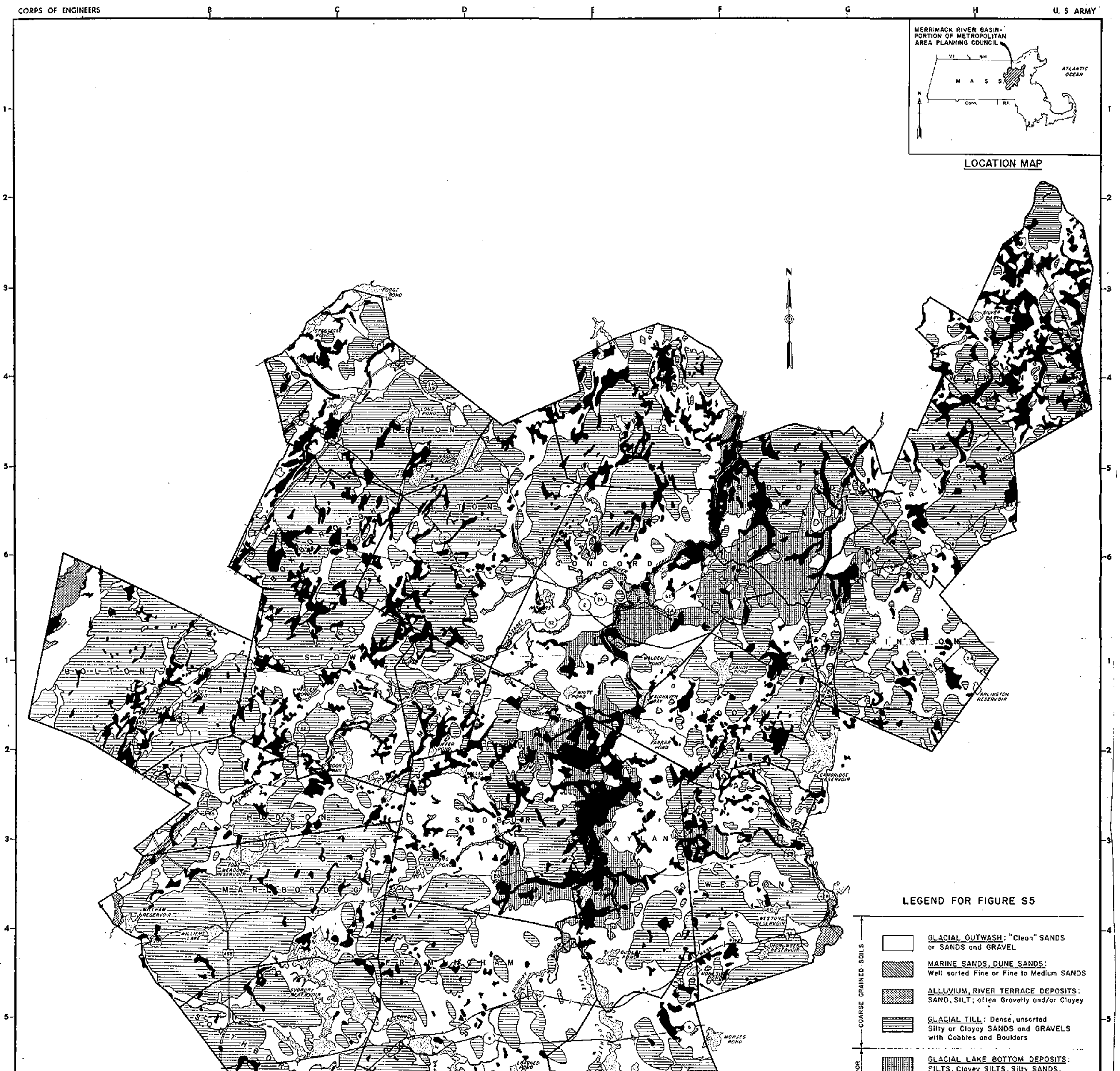
Groundwater favorability for the Merrimack River Basin portion of the Metropolitan Planning Council is mapped in Figure W5. This RPA Area includes the major part of the Assabet drainage basin, which was mapped in detail by the USGS, and is the most reliable in terms of ground water information of all RPA Areas mapped. Essentially all of the northwestern one-half of the map is covered by the USGS information. The remainder of the map is based upon extrapolations of the surficial geology-ground water patterns seen in the USGS coverage.

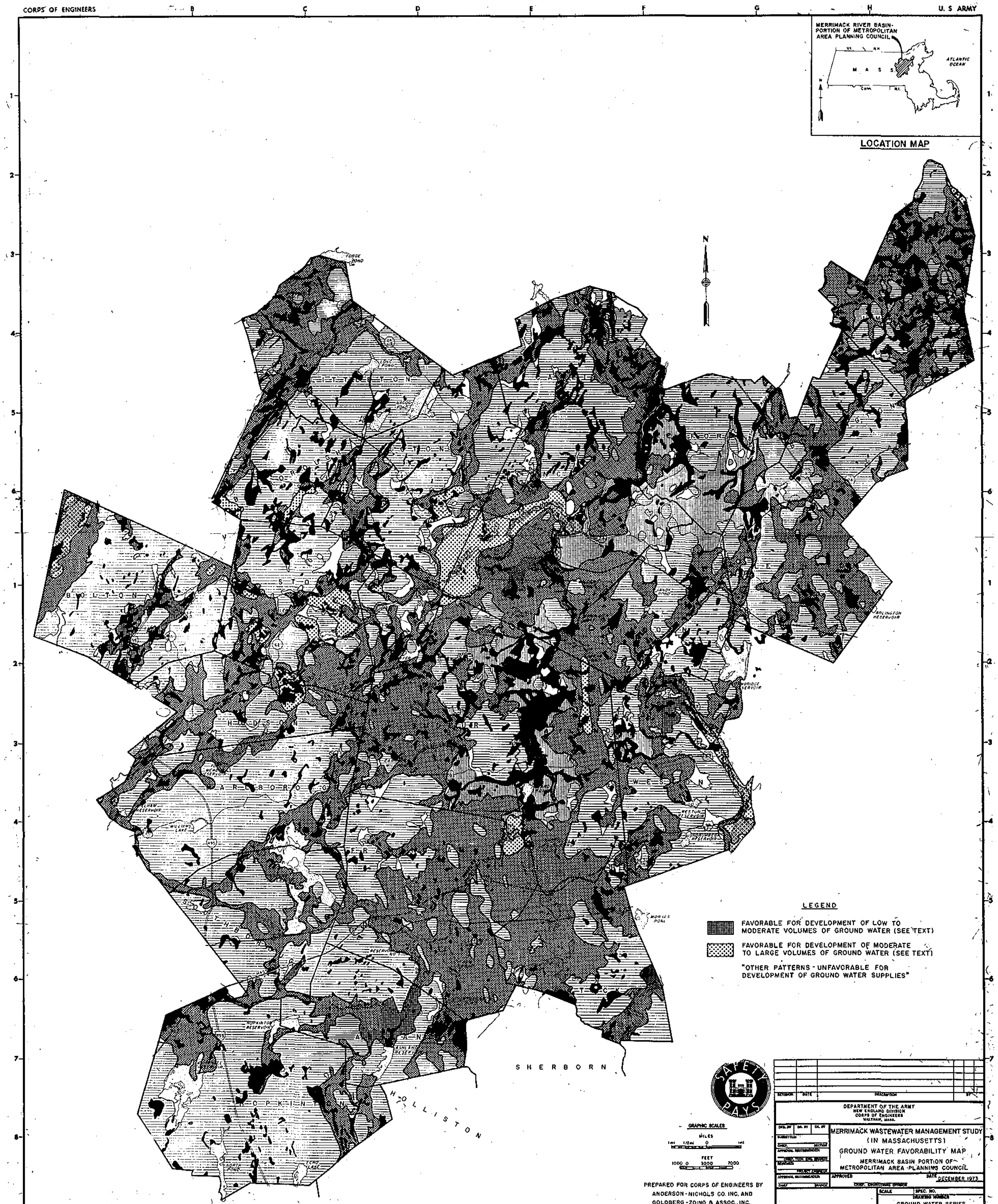
Highly favorable areas for potential development of groundwater supplies (outside of the Assabet) are shown in westernmost Bolton, northeastern Framingham, eastern Wayland, and along the eastern boundary of Weston. The area in West Bolton is a continuation of the buried channel trend extending from Ayer to Wachusett Reservoir, and the area in Framingham is based upon the presence of a highly productive well field. A buried river channel is inferred in the subsurface in Wayland. The highly favorable area along the western border of Weston is an extension of a buried channel which was mapped in detail in the Mystic Lake area, just outside of the mapped coverage. The greatest area of high favorability in the Assabet is at the confluence of the Assabet and Concord Rivers (buried channels, chiefly one, and several smaller areas are present throughout much of the drainage basin).

Moderate favorability is patterned after the relationships for the stratified drift/ice contact and ground water patterns noted in the Assabet drainage basin. A few small areas where glacial till patterns restrict the stratified drift/ice contact patterns to narrow strips are excluded from moderate favorability if no surface evidence of recharge supply is evident. Areas mapped as glacial till are almost exclusively mapped as having poor favorability for development of ground water supply.

Details of the ground water favorability outside of the Assabet could probably be greatly improved with a thorough evaluation of well logs, and by a thorough survey of municipal water supply information.


CORPS OF ENGINEERS
U. S. ARMY
MERRIMACK RIVER BASIN-PORTION OF METROPOLITAN AREA PLANNING COUNCIL
ATLANTIC OCEAN
LOCATION MAP
WILMINGTON
CONCORD
SUDBURY
MARLBOROUGH
FRAMINGHAM
SHERBORN
HOPKINTON
HOLLISTON
ARLINGTON RESERVOIR
CAMBRIDGE RESERVOIR
MORSES POND
NOTE: BEDROCK UNITS IN NATICK QUAD PRIMARILY FROM NELSON, USGS OPEN FILE; 1973
LEGEND FOR 85
IGNEOUS ROCK UNITS
DIABASE DIKES
PEGMATITE BODIES
BEVERLY SYENITE
FITCHBURG GRANITE
ANDOVER GRANITE
STRAW HOLLOW DIORITE & ASSABET QUARTZ DIORITE
ACTON GRANITE
AYER GRANITE
DRACUT DIORITE
NEWBURY AND MATTAPAN VOLCANICS
MILFORD GRANITE
DEDHAM GRANODIORITE
NEWBURYPORT QUARTZ DIORITE
SALEM GABBRO DIORITE
KENDALL VOLCANICS
PROBABLE FAULT
BODY OF WATER (RIVERS, LAKES, PONDS, ETC.)
SEDIMENTARY, META-SEDIMENTARY ROCK UNITS
GNEISSES & SCHISTS (TO OTHER FORMATIONS OR GROUPS)
HUBBARDSTON GRANITE with inclusions of BRIMFIELD SCHIST (BRIMFIELD-WARE) OR PAXTON QUARTZ SCHIST
BOSTON GROUP
CAMBRIDGE SLATE
ROXBURY CONGLOMERATE
GOSPEL HILL GNEISS
NASHOBA FORMATION
BOYLSTON SCHIST
WORCESTER FORMATION
BRIMFIELD SCHIST
WORCESTER PHYLLITE
HARVARD CONGLOMERATE
PAXTON QUARTZ SCHIST
MERRIMAC GROUP
OAKDALE QUARTZITE
MERRIMAC QUARTZITE
CHERRY BROOK FORMATION
MARLBORO FORMATION
WESTBORO QUARTZITE
RICE FORMATION
SAFETY PAYS
GRAPHIC SCALES
MILES
FEET
PREPARED FOR CORPS OF ENGINEERS BY ANDERSON-NICHOLS CO. INC. AND GOLDBERG-ZOINO & ASSOC., INC.
REVISION
DATE
DESCRIPTION
BY
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)
BEDROCK GEOLOGY MAP
MERRIMACK BASIN PORTION OF METROPOLITAN AREA PLANNING COUNCIL
APPROVED
CHIEF, ENGINEERING DIVISION
DATE DECEMBER 1973
SCALE
SPEC. NO.
DRAWING NUMBER
BEDROCK SERIES
SHEET 85


CORPS OF ENGINEERS
U. S. ARMY
MERRIMACK RIVER BASIN-PORTION OF METROPOLITAN AREA PLANNING COUNCIL
ATLANTIC OCEAN
M A S S
LOCATION MAP
LITTLETON
CONCORD
BURLINGTON
LEXINGTON
ARLINGTON RESERVOIR
CAMBRIDGE RESERVOIR
BOLTON
SUDBURY
WAYLAND
WESTON
MARLBOROUGH
FRAMINGHAM
ASHLAND
HOPKINTON
SHERBORN
HOLLISTON
WESTON RESERVOIR
NORUMBEGA RESERVOIR
MORSES POND
LEGEND FOR FIGURE S5
COARSE GRAINED SOILS
GLACIAL OUTWASH: "Clean" SANDS or SANDS and GRAVEL
MARINE SANDS, DUNE SANDS: Well sorted Fine or Fine to Medium SANDS
ALLUVIUM, RIVER TERRACE DEPOSITS: SAND, SILT; often Gravelly and/or Clayey
GLACIAL TILL: Dense, unsorted Silty or Clayey SANDS and GRAVELS with Cobbles and Boulders
FINE GRAINED AND/OR ORGANIC SOILS
GLACIAL LAKE BOTTOM DEPOSITS: SILTS, Clayey SILTS, Silty SANDS, Varved CLAY & SILT
FRESH WATER ORGANICS: PEAT, Sandy or Silty PEAT, "Muck"
BODY OF WATER (Rivers, Lakes, Ponds, etc.)
SAFETY PAYS
GRAPHIC SCALES
MILES
FEET
PREPARED FOR CORPS OF ENGINEERS BY ANDERSON-NICHOLS CO. INC. AND GOLDBERG-ZOINO & ASSOC., INC.
REVISION
DATE
DESCRIPTION
BY
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)
SURFICIAL GEOLOGIC MAP
MERRIMACK BASIN PORTION OF METROPOLITAN AREA PLANNING COUNCIL
DECEMBER 1973
SURFICIAL SERIES
SHEET S5


CORPS OF ENGINEERS
U. S. ARMY
MERRIMACK RIVER BASIN-PORTION OF METROPOLITAN AREA PLANNING COUNCIL
ATLANTIC OCEAN
MASS
LOCATION MAP
N
BOLTON
SHERBORN
HOLLISTON
ARLINGTON RESERVOIR
WESTON RESERVOIR
LEGEND
FAVORABLE FOR DEVELOPMENT OF LOW TO MODERATE VOLUMES OF GROUND WATER (SEE TEXT)
FAVORABLE FOR DEVELOPMENT OF MODERATE TO LARGE VOLUMES OF GROUND WATER (SEE TEXT)
"OTHER PATTERNS - UNFAVORABLE FOR DEVELOPMENT OF GROUND WATER SUPPLIES"
SAFETY PAYS
GRAPHIC SCALES
MILES
FEET
1000 0 3000 7000
PREPARED FOR CORPS OF ENGINEERS BY ANDERSON-NICHOLS CO. INC. AND GOLDBERG-ZOINO & ASSOC., INC.
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK WASTEWATER MANAGEMENT STUDY
(IN MASSACHUSETTS)
GROUND WATER FAVORABILITY MAP
MERRIMACK BASIN PORTION OF METROPOLITAN AREA PLANNING COUNCIL
DATE DECEMBER 1973
GROUND WATER SERIES
SHEET W5

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SECTION III - C

FINDINGS - 20 SITE INVESTIGATIONS

MERRIMACK WASTEWATER MANAGEMENT STUDY

TABLE 4

SUMMARY OF EVALUATION OF 20 SITES*

Site No.	Location	Total Area Acres	Zone	Suitability for R.I.	Suitability for S.I.	Suitability for O.R.	Confidence in Evaluation
1	Holden	450		Good	Fair	No Good	High
2	Haverhill	500		Fair/Good	Fair	No Good	Moderate/High
3	Merrimac	670		Poor/Fair	Fair	Poor	Moderate
4	Acton	615		Poor	Fair/Good	Fair	Moderate/High
5	Westford	505	I	No Good	Poor	Good	High
			II	Poor	Fair/Good	Poor	Moderate
6	Pepperell	160		Poor/Fair	Fair/Good	Fair/Good	Moderate
7	Dunstable and Pepperell	304		Poor	Fair/Good	Poor	High
8	Stow	230		Fair/Good	Good	Poor	Moderate/High
9	Marlborough	430		No Good	Poor	Poor	High
10	Fort Devens	215		Good	Fair	No Good	High
11	Sterling	450		No Good	Poor	Poor	High
12	Amesbury	387		Poor	Fair	Fair	Moderate
13	Newburyport	366		Fair	Good	Poor	Moderate
14	W. Newbury	670		No Good	Poor/Fair	Poor	High
15	Boxford	686		No Good/Poor	Fair/Poor	No Good	Moderate
16	Dracut	720		Poor	Fair/Good	Poor	Moderate/High
17	Concord	225		Fair	Fair/Good	Poor	Moderate
18	Concord	500		Fair/Good	Good	Poor	Moderate/High
19	Ashby	650 (total)	I	No Good	Poor	No Good	High
			II	No Good	No Good	No Good	High
			III	Good	Fair	No Good	Moderate
20	Wayland	365		Poor	Poor	Poor	High

Note: R.I. Indicates Rapid Infiltration Pond
S.I. indicates Spray Irrigation
O.R. indicates Overland Runoff

*Evaluations are based on existing site conditions. These evaluations could be upgraded with site design and management.

and occasional large boulders.

At the south end of the site, examination of a roadway cut indicated poorly developed topsoil overlying fine sand, little to some medium to coarse sand and fine to coarse gravel (rounded), trace silt.

Surface boulders were noted on the extreme northeast and southeast sections of the site.

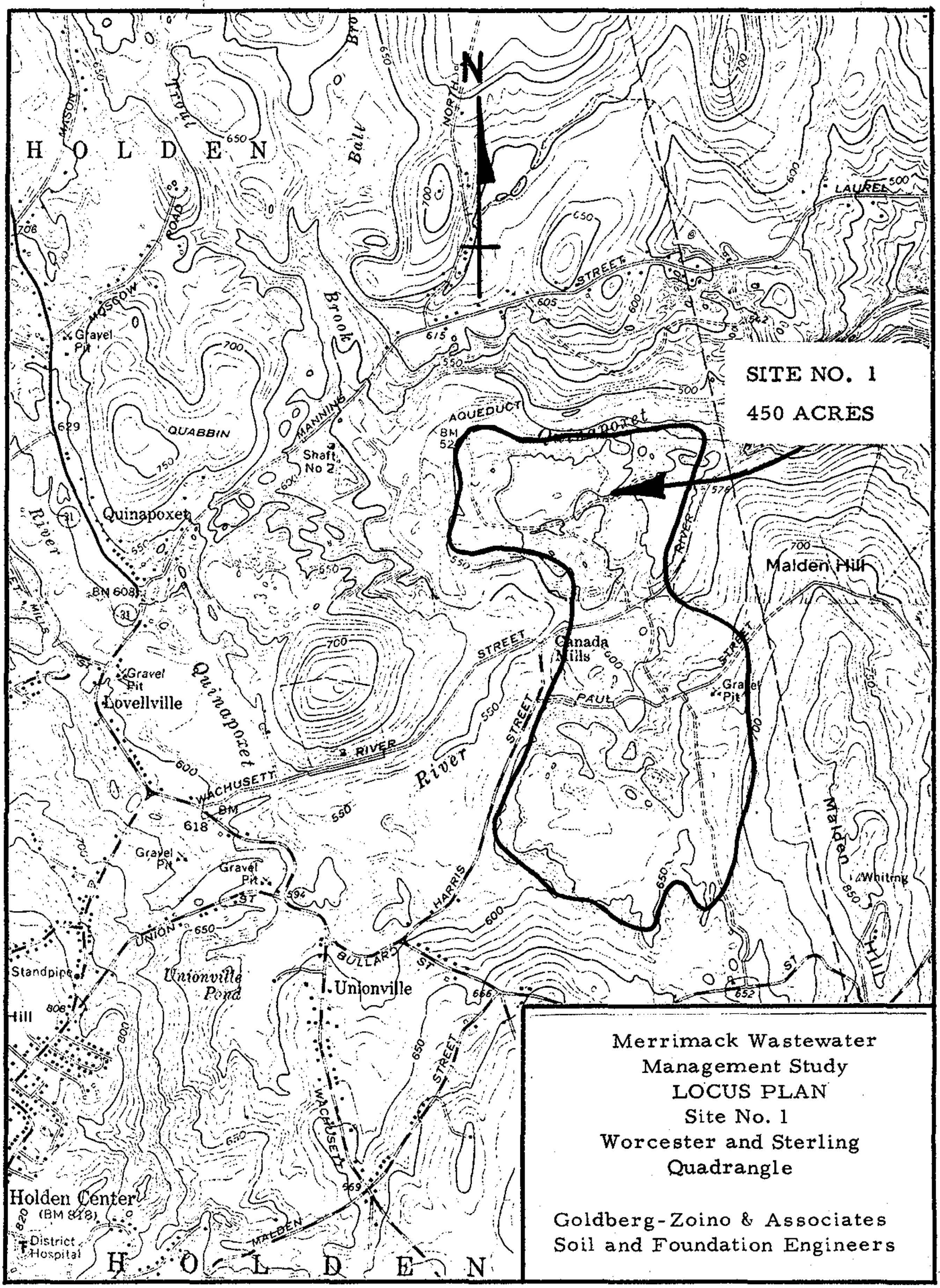
Ground water will be relatively deep in the terrace areas and will be controlled by surrounding swamps, ponds and rivers. Ground water is believed to be at or below elevation 570 in the northern section and below elevation 600 in the southern section. At the contacts with glacial till zones, ground water may be found at the surface of the till in wet seasons. Ground water is also at the surface in kettle hole swamps and ponds.

OVERALL EVALUATION OF SITE

Generally the site contains deep deposits of pervious soils with deep water table. Consequently the site may be well suited for rapid infiltration methods of waste-water treatment with the exception of glacial till areas and the steep slopes at the terrace edges.

The site may have fair possibilities for spray irrigation but this could be limited by the high permeability of the soils as well as steep slopes at the edges of the terraces.

The site is not considered good for overland runoff because of the relatively high soil permeability.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 1
Worcester and Sterling
Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTEWATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE NO. 2

SITE LOCATION

The site is located along the west bank of the Merrimack River in Haverhill, Massachusetts. Its area is bounded to the west by East Broadway Street and the Millvale Reservoir, to the north by Rocks Village, and to the south by Millvale Road. The site includes about 500 acres, much of it heavily forested by White Pines. New homesite construction is underway along East Broadway Street, some of it exclusive to the degree that we were unable to obtain access rights.

AVAILABLE DATA

The data available for use prior to our on-site inspection included the U.S.G.S. Haverhill Quadrangle Topographic Map; U.S. Department of Agriculture Soils Map for Essex County (1925), B.K. Emerson's Bedrock Geology Map of the State, and Clapp's Geology of the Igneous Rocks of Essex County. In addition a report by Goldberg-Zoino & Associates, Inc. on the geology and groundwater conditions of a nearby school site was reviewed (located immediately northwest of Kimball Hill).

GENERAL SITE DESCRIPTION

The site included a series of large hills overlooking the Merrimack River. Of these, Kimball Hill to the north is the largest. Lowlands among the hills are either heavily wooded residential areas or farmed river terraces. Swampy areas, other than limited low lying alluvial flats, are lacking. The site relief varies from less than two percent along terraces to more than 30 percent as virtual bluffs along the river.

BEDROCK

Shallow bedrock along a portion of the river is reported by the U.S. Department of Agriculture Soils Map. Unfortunately, this area is that portion of the site from which we were excluded. Its location is a ±1500 foot strip along the river beginning about 2000 feet south of Greenwood Cemetary. We were also prohibited from entering much of the Kimball Hill area. Bedrock outcrops other than those which may exist in these areas were not observed. If, as Emerson and Clapp state, the bedrock in the vicinity is the Merrimack Quartzite, then it would be either a slatey quartzite or biotitic quartz schist.

Depths to bedrock at the site remain questionable. However, seismic information on the nearby school site indicates that rock was encountered at depths of from 70 to 90 feet (El. 55' to 85').

SOILS

Soils of three types in the site area are identified on the U.S. Department of Agriculture Soils Map. We were able to confirm at least two of the three.

The majority of the site is underlain by deep sands and sands with gravel. A large gravel pit operation was in progress during the time of this examination. It is located opposite the Greenwood Cemetary along East Broadway Street. More than 50 feet of "clean", well-sorted and stratified sands, and sands with gravel were observed. Their occurrence extended for several hundred feet north and south of the gravel pit entrance, and other indications led us to believe that they may occur under 50 to 75% of the site area. We were able to note and record the presence of similar stratified sands and sandy silts further south near the Millvale Reservoir. These soils differed somewhat in that they included thick stratified layers of silt. Soils in the major parts of the site have been identified on the U.S. Department of Agriculture map as the Hinckley gravelly sandy loam and the Merrimack loamy sand; both types are reportedly derived from glacial outwash material occurring as kames or in glacial terraces.

A second soil; dense, unsorted fine to coarse sand and gravel with cobbles and boulders and 20 to 30% silt, occurs beneath Kimball Hill and is reported to occur in another unnamed hill east of Broadway Street(about midway between the northern and southern bounds of the site). A boring taken at the toe of Kimball Hill, on the north side of East Broadway Street, shows the following:

El. ± 80'	Depth	Soil Description
	0'	
		Dark brown loamy SAND
	2'	
		Hard fine to coarse brown SAND and GRAVEL, trace of Clay (GLACIAL TILL)
	16.5'	
		Bottom

Other borings in the vicinity indicate that similar soils continue toward the northwest. The U.S.D.A. Map refers these soils to the Woodbridge loam material derived from glacial tills.

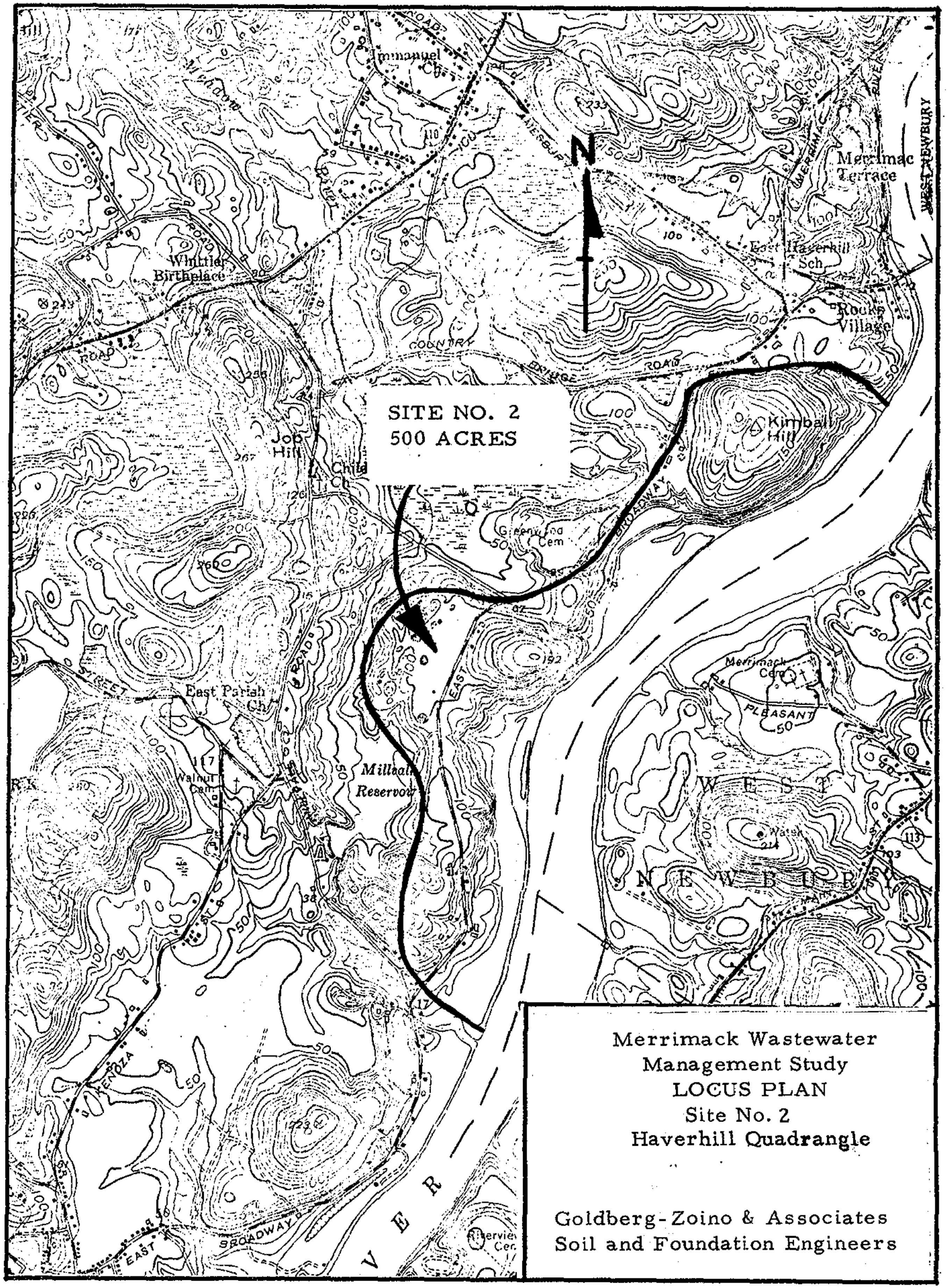
Alluvium reportedly occurs along the Merrimack River occupying low lying terraces and alluvial flats. It has been mapped as the Ondawa very fine sandy loam.

GROUNDWATER

Groundwater levels will vary greatly. Along the Merrimack, in terraces and flats, its elevations will mirror those of the river. Among the outwash deposits groundwater levels may be deep. Borings among the stratified sands and gravels west of the site show groundwater at depths of from 20 to 50 feet. In glacial tills groundwater levels will fluctuate seasonally, but generally they will occur at depths between 4 and 10 + feet. Observation wells should be installed in order to obtain more definitive information on the water levels.

EVALUATION OF SITE

The unique shape, location and topography of this site will, to a certain degree, control its use for sewage treatment. Severe slopes toward the Merrimack River and pervious soils eliminate its use for overland runoff treatment. Similarly, these conditions will limit its use for spray irrigation in substantial portions of the site. However in sectors of the site where sufficient length of effluent travel may be maintained, the site is highly suitable for rapid infiltration treatment.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 2
Haverhill Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTE WATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #3

SITE LOCATIONS

The site is located wholly within the town of Merrimac. It is bounded to the northwest by the New Hampshire State line, on the north and west by Highland Street, on the west by Newton Street, and to the south by Hadley Road. The site area includes some 670 acres, much of which is heavily wooded. One unpaved roadway partially bisects the area, and leads to the Merrimac Town Dump also located within the site bounds.

AVAILABLE DATA

The data available prior to the site visit consisted of a soil map by the U.S. Department of Agriculture (Essex County, 1925),B.K. Emerson's Bedrock Geology Map for the State of Massachusetts, and Clapp's Geology of the Igneous Rocks of Essex County, Massachusetts. In addition, the surrounding areas in New Hampshire north and west of the site have been mapped by Billings (The Geology of New Hampshire- 1:250,000 scale), and by Edward Bradley (Geology and Ground Water Resources of Southwestern New Hampshire).

GENERAL SITE DESCRIPTION

The site area includes two hills: Highlands Hill and Red Oak Hill. Swampy low ground areas abut the site immediately to the south but they are, for the most part, outside the described area's bounds. Slopes vary from 3 percent to more than 25 percent, the latter occurring along the southern side of Red Oak Hill. The total relief on the site is greater than 185 feet.

BEDROCK

Definitive bedrock exposures were not noted on the site. However, scattered and isolated large boulders were seen; some of which may have represented bedrock outcrops.

The bedrock reported by Emerson, Clapp and Billings for this area is the Merrimack Quartzite, a meta-sedimentary rock. Typically the Merrimack Quartzite is a grey, slatey to schistose rock comprised of quartzites, quartz-mica schists, biotitic schists, and phyllites.

Stone fences were noted throughout the site. These were primarily made up of rounded cobbles and small boulders of several rock types, presumably they were derived from the bouldery soils on or near the site.

SOILS

Soils described from New Hampshire areas immediately adjacent to the site are mostly glacial tills (to the north and west). Sand and gravel outwash and ice-contact deposits occur to the southwest. Observations of cellar holes within the site area verified the occurrence of glacial till. One such hole reached approximately 8 feet in depth. It was located along Newton Street, nearly midway between the New Hampshire state line and Hadley Street. A log of that hole shows:

Depth	
0'	Dark gray to black Humus, SAND and SILT (TOPSOIL)
0.5'	Yellow brown SILT and fine to medium SAND, little coarse Sand and Gravel (SUBSOIL)
1.5'	Gray brown fine to coarse SAND, GRAVEL, COBBLES and BOULDERS, some Silt
8.0'	Dense, unsorted, unstratified mixture (GLACIAL TILL)

This observation was made in an area identified on the U.S. Department of Agriculture Soils Map as Gloucester Loam- a soil derived from glacial till.

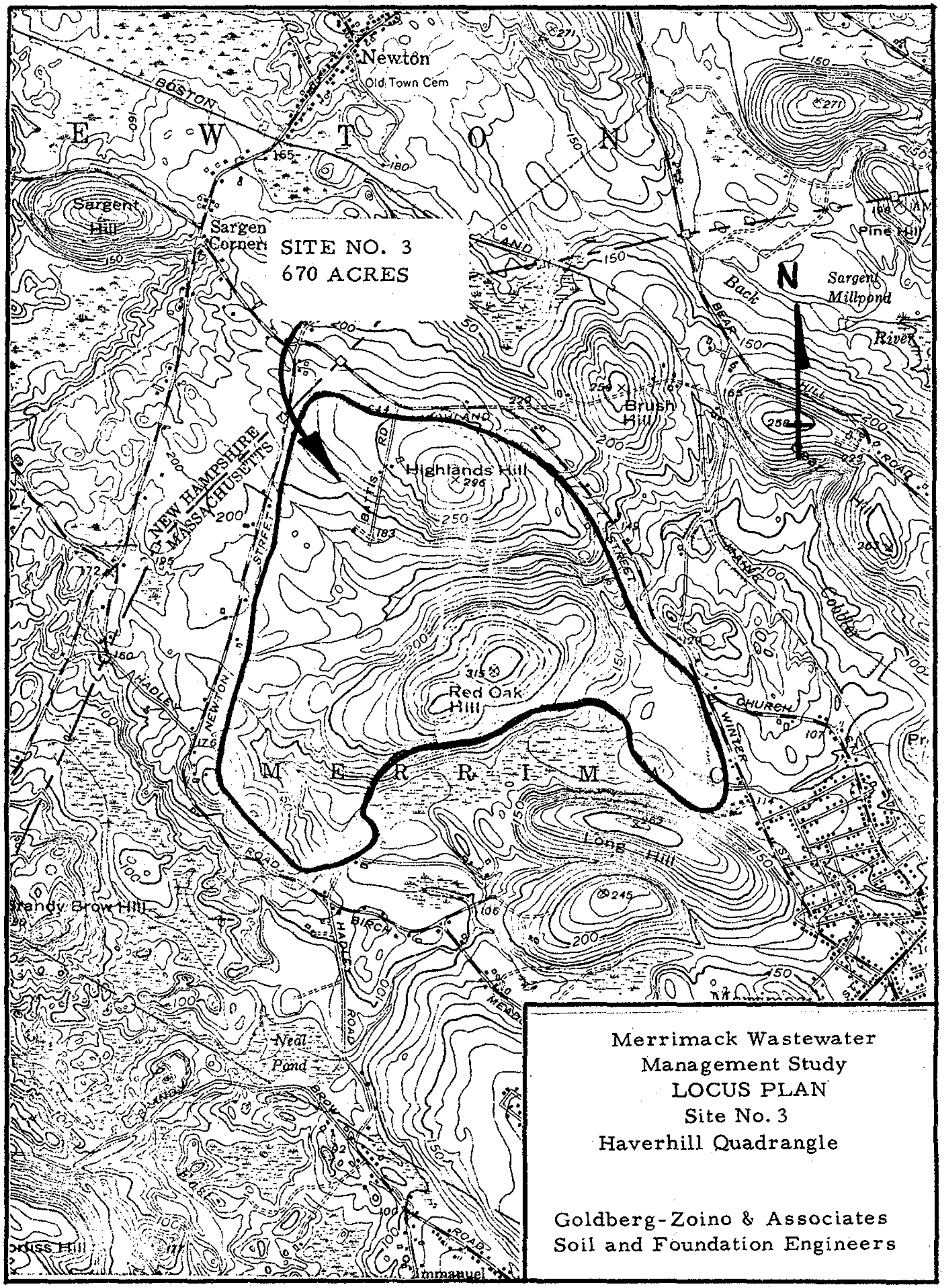
Large scale gravel pit operations were in evidence immediately south and west of the site. From an elevated vantage point on Newton Road, stratified sands and gravels could be observed off the site for a considerable distance. These deposits, however, appeared to occur at lower elevations (up to Elevation 150'). Their extension onto the site area is probably limited to the extreme south, near Hadley Road and along the eastern edge of the site near Winter and Highlands Streets. Some evidence of this was seen near the latter location; here an abandoned and overgrown roadway cut exposed silty fine to medium sands with boulders representing either a poorly sorted outwash deposit, or reworked glacial till. This observation was made in an area identified by the U.S. Department of Agriculture Soils Map as the Merrimack Sandy Loam- a soil derived from glacial outwash materials.

GROUND WATER

The position of the ground water table would have to be determined by observation wells throughout the site. Standing water exists south of the site in the swampy area mentioned above at elevation ±130 . On the site somewhat wet conditions were noted along low ground between Highlands Hill and Red Oak Hill (near the Merrimac Dump); these conditions occurred at Elevations 140' to 150'. Elsewhere there was little evidence of high ground water. It is estimated that under the majority of the site ground water would be found at depths of 5' to 10' or more. This would be expected to vary throughout the year in accordance with seasonal phenomena.

EVALUATION OF THE SITE

Based on our site examination and the available data, it is believed that the site is primarily underlain by glacial till and would therefore have limited value for rapid infiltration treatment. The possible exceptions to this are the extreme southern portions of the site where sand and gravel layers may exist which are continuous with the large deposits toward the southwest. Those portions of the site which are flanks of the large hills would have little value for either spray irrigation or overland flow (because of steep slopes). However, center portions of the area between the hills may be acceptable for spray irrigation.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 3
Haverhill Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTEWATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #4

SITE LOCATIONS

The site is located mostly within the town of Acton, Massachusetts near the intersection of Route 27 and Route 119. A small portion of the site, namely the northeastern corner, is located within the town of Carlisle, Massachusetts. The site is bounded on the west by Nashoba Brook and by Carlisle Road. It is bounded on the north by Acton Street and on the east by West Street. The southern extremity is latitude 42°30'. The site encompasses approximately 615 acres as shown on the Locus Plan.

AVAILABLE DATA

The information available prior to our site visit consisted of the U.S.G.S. Westford, Massachusetts Topographic Quadrangle Sheet dated 1966; the U.S. Department of Agriculture Soil Conservation Service Soil Map, Middlesex County, Massachusetts, 1924; and the Bedrock Geology Map of Massachusetts and Rhode Island, B.K. Emerson, 1916.

GENERAL SITE CONDITIONS

The principal site features are two rather large hills, each having a relief of about 100 feet. One of the hills is in the northeastern portion of the site and the other hill is in the southeastern portion of the site. The latter hill is the northwesterly extension of Strawberry Hill. The site is moderately to heavily wooded with evergreens in predominance. Slopes are slight to moderate, generally ranging from about 3 to 8 percent. The steepest slopes exist on the western flanks of the two hills where slopes reach a maximum of 7 to 9 percent. A broad area in the central and southeastern portion of the site has gentle slopes of the order of 2 to 4 percent.

BEDROCK

According to the geological map by B.K. Emerson, the principal bedrock types at the site are gneisses and schists of undetermined age. One bedrock exposure was noted in the road cut adjacent to West Street in the northeast portion of the site. This outcrop exists as a closely-jointed, highly-weathered micaceous schist. Within the large hill in the northeast portion of the site, bedrock is expected to exist within depths of 5 to 10 feet from existing ground surface. No bedrock exposures were noted in the southern portions of the site and it is inferred that bedrock is deeper in this area. An estimate of 10 feet or more is considered possible within the southern portion of the site.

SOILS

Soil conditions throughout the site may be described principally as glacial till formations. These glacial tills are quite sandy and in some areas contain considerable surficial boulders. According to the map of the Soil Conservation Service the following soil types are present at the site in the indicated percentages:

Symbol	Name	Soil Group	Approximate Percent
G	Gloucester stony sandy loam	1	25%
Gr	Gloucester stony fine sandy loam	1	25%
Bt	Brookfield stony loam	5	20%
Br	Brookfield stony sandy loam	5	10%
Ga	Gloucester stony loamy sand	1	10%
Mc	Merrimack loamy sand	2	5%
Mg	Merrimack gravelly sandy loam	2	5%

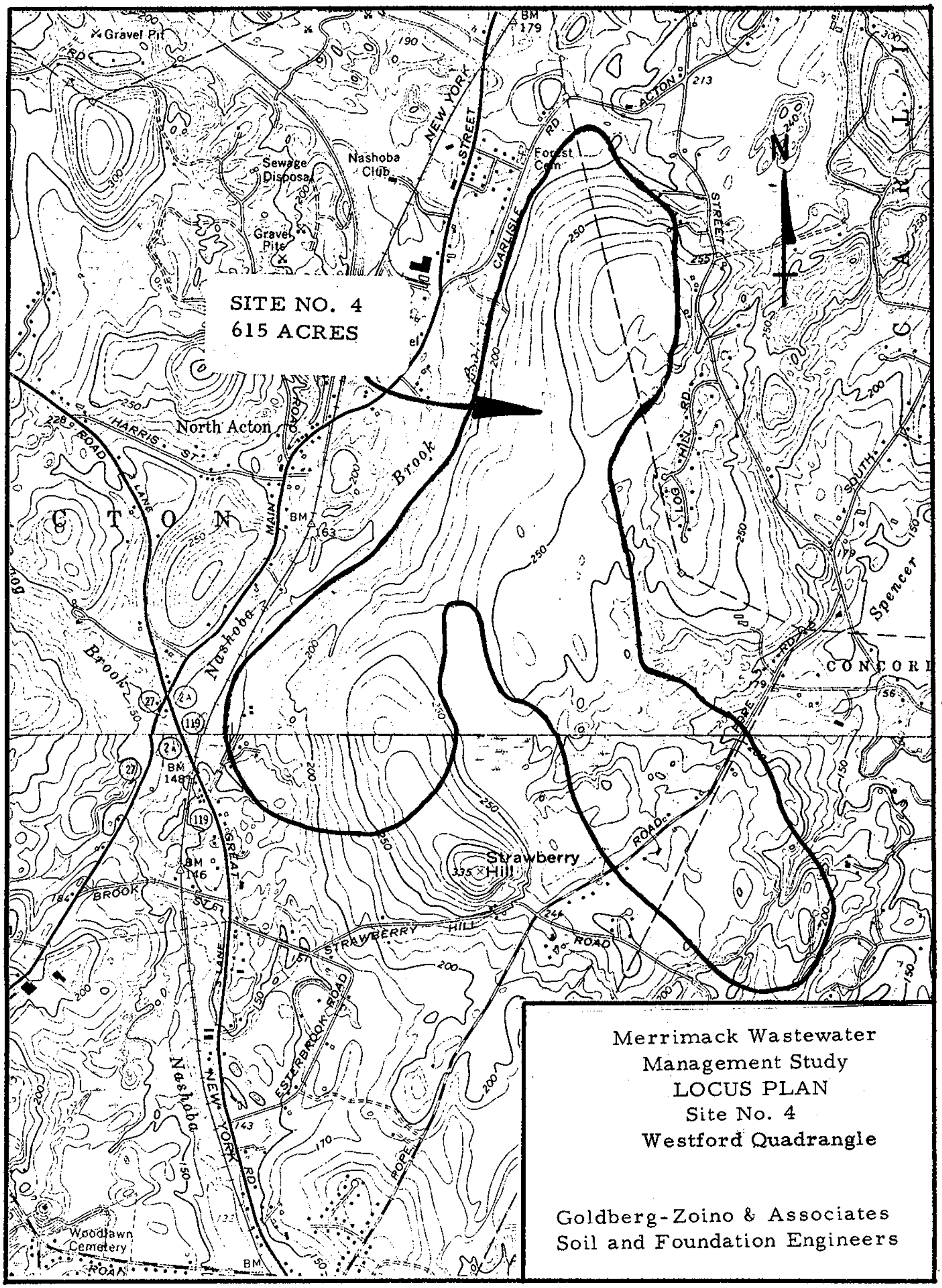
A sample was obtained within an excavation for a new residence adjacent to West Street in the area mapped as Brookfield stony sandy loam. This sample may be visually described as light brown fine sand, trace medium sand, little silt. The silt fraction (material passing U.S. Standard #200 sieve) is non-plastic and represents approximately 15 to 20 percent of the total sample. At this particular location somewhat angular surficial boulders up to 3 feet in size were noted. Bedrock consisting of weathered schist was encountered at a depth of 4 to 5 feet below pre-existing ground surface. The soils appear to be relatively pervious within the spectrum of glacial till permeabilities.

GROUND WATER

Ground water was noted within topographical low areas such as adjacent to Nashoba Brook, Log Hill Road, and in the saddle between the higher flanking ground at the southern portion of the site. Ground water was not noted within depth of 5 feet at the previously - mentioned excavation. However, this observation was made during October and it may represent a seasonal low. Ground water is expected to vary throughout the year in accordance with seasonal phenomena. Generally speaking, ground water would be expected within depths of 5 feet from existing ground surface in the eastern portions of the site. It may be somewhat deeper (estimated 5 to 10 feet deep) on the well-drained slopes forming the western flank of the site area.

OVERALL EVALUATION OF SITE

In general, the limiting features of the site with respect to land treatment methodologies for wastewater may be described as glacial till overlying shallow bedrock with slight to moderate slopes and moderate drainage. Accordingly, the site would be rated poor in terms of use for rapid infiltration principally because of the depths to bedrock and ground water table. The site would be rated fair for overland runoff. The principal limitation for overland runoff being the moderate to high permeability in the upper soils. For example, a percolation test made for the previously mentioned residence indicated a rate of 5 minutes per inch at a depth of about 3 feet from existing ground surface. The site would be rated fair to good for use of spray irrigation. The limiting feature for this method is the possible shallow depth to bedrock in certain areas. This would have to be determined before any final assessment could be made.



Merrimack Wastewater Management Study
LOCUS PLAN
Site No. 4
Westford Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTE WATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #5

SITE LOCATION

The site is located partly in Littleton and partly in Westford, about one mile northwest of the interchange of Routes 119 and 495 and within the U.S.G.S. Westford Quadrangle.

AVAILABLE DATA

Available published data are: U.S.G.S. Westford Quadrangle Topographic Map; Middlesex County Soil Survey (U.S. Department of Agriculture) dated 1924; and the Bedrock Geology Map for Massachusetts prepared by B.K. Emerson, dated 1917.

GENERAL SITE DESCRIPTION

The site encompasses approximately 505 acres of which about 80 percent is wooded and the remaining 20 percent is predominantly farm land presently under cultivation.

As noted on the Locus Plan the site has been subdivided into two zones. Zone I, which occurs above about elevation 240, is characterized by glacial till over relatively shallow bedrock. Zone II, consists of glacio-fluvial deposits on the flanks of the hill contiguous with the adjoining swamp and Forge Pond to the north. Within Zone I surface vegetation consists primarily of hardwood forest, principally oak and maple. Scattered evergreens occur through these forests. Within Zone II vegetation consists primarily of mature evergreens (white pine) with scattered hardwoods in the forest. A tree farm is sited in this latter area.

Typically slopes in Zone I are about 4 percent to 5 percent. Slopes are regular but occasional knobs of apparent shallow bedrock occur. Within Zone II the topography in the western sector is highly variable. Slopes range from essentially flat to about 10 percent along the sides of knobs. To the east the ground slopes gently at about 1 to 2 percent toward the swamp and then displays a steeper ice contact face along the margin of the swamp.

Very few residences exist within this site. A few scattered houses exist along Beaver Brook Road and a farm is located in the northwest portion of the site. A large electrical transmission line crosses this site from east to west and the Littleton Electric Co. Substation is on Beaver Brook Road near the power line.

BEDROCK

Emerson identifies two bedrock types on this site with the contact zone between the two running approximately northeast/southwest. Bedrock to the southeast is identified by Emerson as Brimfield schist, while bedrock to the northwest is identified as Ayer granite. Many exposures of both rock types were observed, particularly in road cuts along Beaver Brook Road and Route 119.

Emerson describes Ayer granite as "typically a biotite-muscovite granite of moderately coarse grain." He describes the Brimfield schist as a "uniform coarse red-brown muscovite schist containing much biotite, fibrolite and graphite, and so much pyrite that it is wholly rusted in many of the deepest openings."

Within Zone I bedrock is believed to be typically shallow. Exposures in cut slopes revealed bedrock at or within 2 feet of the surface. Also bedrock knolls were noted along the power line cut. Under these circumstances it is believed that average bedrock depth is probably within ten feet of the surface.

Within Zone II it is suspected that bedrock depth may be quite erratic in the western portion. (Bedrock mapped as Ayer granite.) Knobby protrusions were noted in several areas and are believed to be bedrock controlled.

SOILS

Zone I (Till)

The basis of interpretation is visual examination of conditions, consideration of published data, and reference to a soils investigation report prepared by this firm at the site of the Littleton Electric Co. Substation. The Middlesex County Soil Survey classifies the soil as a Gloucester sandy loam or Charlton fine sandy loam. It is believed that these soils contain about 30 percent passing the No. 200 sieve, that this fraction is non-plastic, and that the soil is well-graded through the sand and gravel range. Topsoil and subsoil are reported about 24 inches thick and are described as friable, sandy loam.

It should be anticipated that rather large ground water fluctuations will occur within Zone I during the yearly season. The yearly high will probably be less than 3 or 4 feet and the yearly low will probably be between 5 and 10 feet.

Zone II (Glacio-fluvial)

Soils are glacio-fluvial deposits, primarily clean fine to coarse sands with trace fine gravel. Exposures were noted in housing excavations, road cuts, abandoned borrow pits, and along the power line route. Soil Conservation Service mapping in Zone II includes the following: Merrimack loamy sand to the north, Charlton fine sandy loam and Charlton stony fine sandy loam to the east, and Hinckley gravelly sandy loam to the southwest.

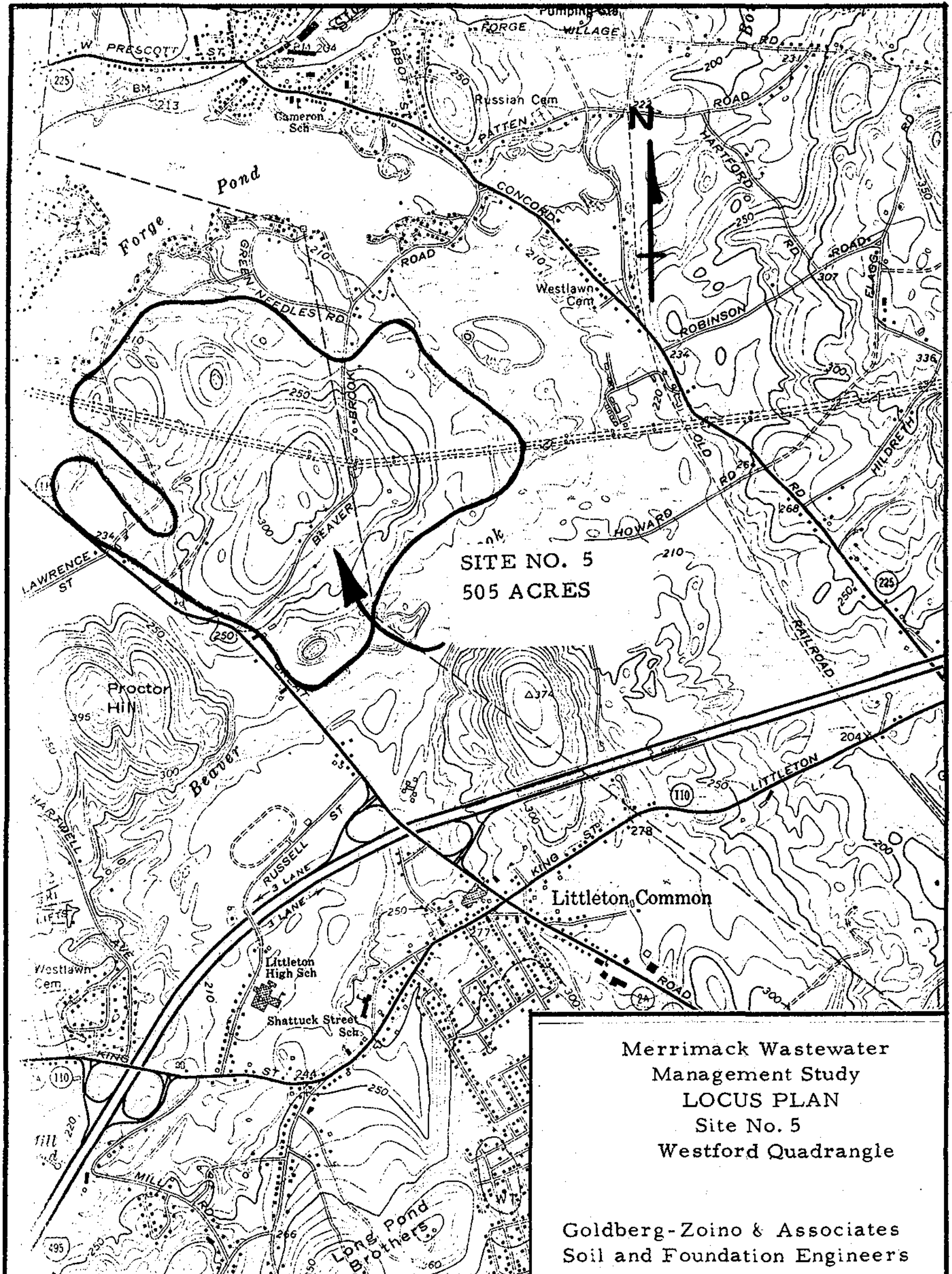
It is expected that ground water will generally be within 5 feet of the surface below elevation 220 in the northwest portion of the site. In the area of relatively flat topography at about elevation 230 (adjacent to Route 119 in the southwesterly sector) ground water is anticipated below 10 feet. On the eastern side, ground water is anticipated between depths of 5 and 10 feet.

OVERALL EVALUATION OF SITE

In summary, the controlling features within Zone I are glacial till over shallow bedrock with high ground water table and slopes typically 4% to 6%. Within Zone II the controlling features are pervious soils, variable topography and possible local shallow ground water in topographical lows. Accordingly the following overall evaluations for treatment of waste water at this site are as follows:

	Zone I	Zone II
Rapid Infiltration	no good	poor
Spray Irrigation	poor	fair/good
Overland Runoff	good	poor

A combination usage of overland runoff at high elevation (Zone I) to a collector system and then to spray irrigation at lower elevation (Zone II) may be considered.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 5
Westford Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTE WATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #6

SITE LOCATION

The site is located about one mile northwest of the town of Pepperell, Massachusetts in an area known as Hovey Corner. The site is bounded by Park Street on the west, by Prescott Street on the northwest, by Brookline Road on the northeast and east, and by a line one-half mile north of Hollis Street on the south. The site encompasses approximately 160 acres as shown on the Locus Plan.

AVAILABLE DATA

The data available to us of a published nature consists of the U.S.G.S. Pepperell, Massachusetts-New Hampshire topographic map; U.S. Department of Agriculture Soil Map of Middlesex County, Massachusetts, 1924; Bedrock Geology Map of Massachusetts and Rhode Island by B.K. Emerson, 1916; Surficial Geology Map of the Pepperell Quadrangle by Carl Koteff and R.P. Volckmann (open file map- unpublished).

GENERAL SITE CONDITIONS

The site is a gently sloping area having slopes of about 2 to 3 percent. The site slopes from west to east toward Brookline Road and ultimately to the Nissitissit River, adjacent to Brookline Road (which intersects the Nashua River about one mile east of the site). There is a man-made brook emanating from springs on the site which zigzag from west to east on the northern portion of the site. Approximately 40 percent of the site is open fields or farm land and approximately 60 percent of the site is heavily to moderately wooded.

BEDROCK

No bedrock exposures were noted during the site examination. However, according to the geological map prepared by B.K. Emerson, the underlying bedrock is the Oakdale quartzite, a "fine, even-grained, flaggy quartzite, in many places greatly jointed, reddish brown from the development of secondary biotite in minute scales." The depth to bedrock is not known. However, angular shaped rock fragments within the soil mantle may provide an indication that bedrock is relatively shallow within the general area. Accordingly, it is estimated that bedrock may be of the order of 20 feet, more or less, from the existing ground surface. This estimate would have to be verified by test borings or geophysical explorations conducted at the site.

SOILS

According to the surficial geology map, the underlying soils consist of glacial till. This formation appears as a brown fine sand and silt, trace fine gravel with subangular boulders generally one foot to three feet in size. This glacial till is non-plastic and may be described geologically as a "sandy" till. At lower elevations, particularly near the southeast corner of the site, the material appears as a fine to medium sand and gravel, trace silt. The material in this area is considerably more pervious than the remaining area which has an appreciable quantity of silt within the glacial till.

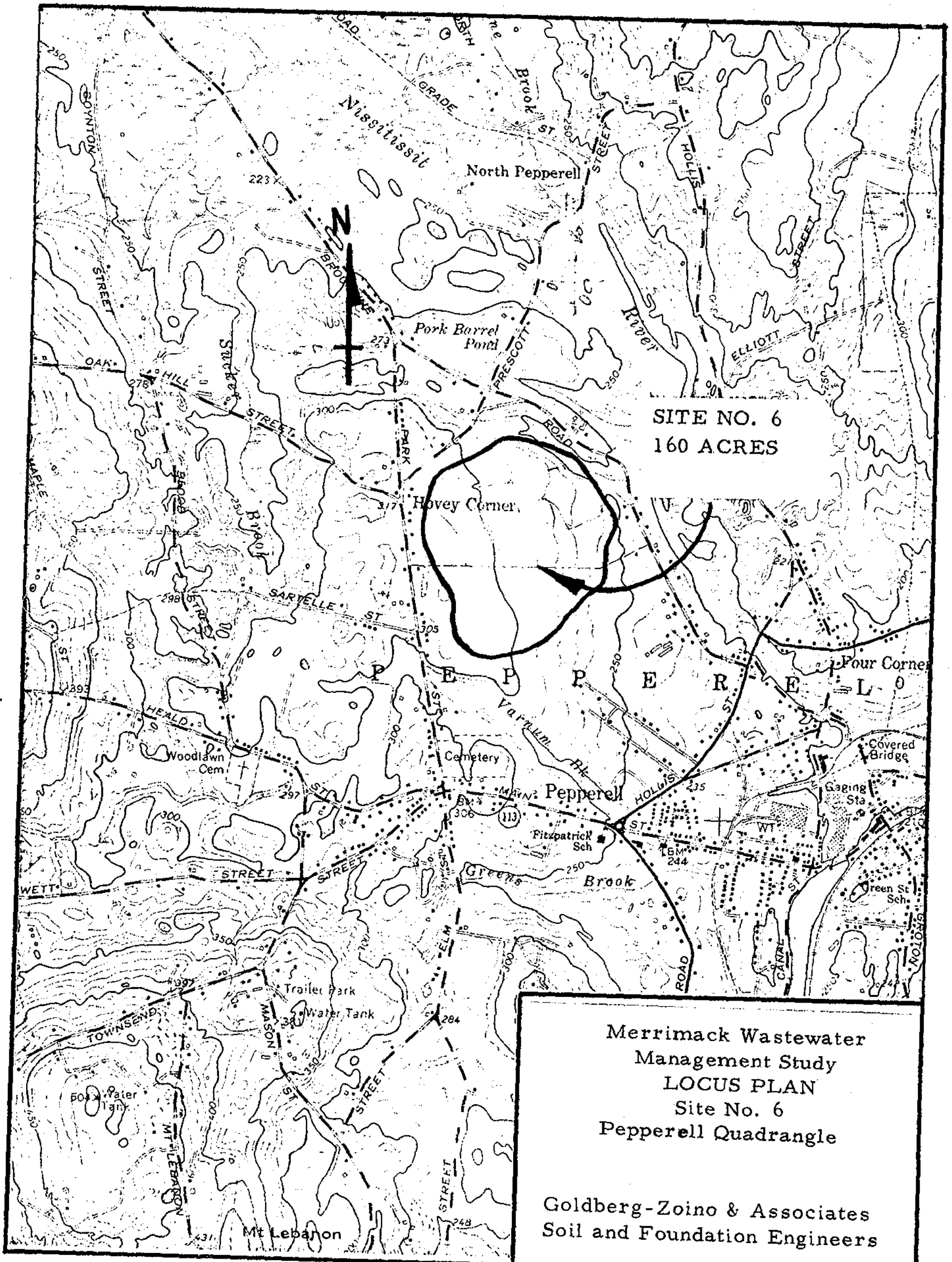
According to the Soil Conservation Service mapping, the glacial till formation at the site is part of the Hollis fine sandy loam except for a very small area adjacent to a small brook in the northeast portion of the site near Brookline Road. According to the soil groupings adopted for this study, the Hollis formation is in Group 6.

GROUND WATER

The site appears to be well-drained and the ground water depth is estimated to be at depths of 5 to 10 feet below existing ground surface except in the vicinity of the brooks crossing the site where ground water is close to the surface. The ground water table will vary throughout the area in accordance with seasonal phenomena.

OVERALL EVALUATION OF SITE

Because of the gentle slopes and the sandy nature of the glacial till, it is expected that the site would be fair to good for use in spray irrigation. We would rate the site as poor to fair for use in rapid infiltration because of relatively high ground water table and the probable relatively shallow depth to bedrock. It would be rated fair to good for overland runoff because of the slopes and low relative permeability of the soils. The degree of contingency in these assessments is considered moderate. Extensive on-site explorations and test borings would be required to arrive at a final conclusion, particularly with respect to the ground water table, depth to rock, and permeability of the soils, and hence the degree to which spray irrigation or overland runoff could be used.



Merrimack Wastewater Management Study
LOCUS PLAN
Site No. 6
Pepperell Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTE WATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #7

SITE LOCATION

The site is located partly within the town of Pepperell, Massachusetts and partly within the town of Dunstable, Massachusetts. The site encompasses some 304 acres as shown on the accompanying Locus Plan. The site is bounded on the west by East Street (Pepperell, Massachusetts) and River Street (Dunstable, Massachusetts), by Unkety Brook on the east, and by Lowell Road (Route 113) on the south.

AVAILABLE DATA

The data available to us of a published nature consist of the U.S.G.S. Pepperell, Massachusetts-New Hampshire topographic map; U.S. Department of Agriculture Soil Map of Middlesex County, Massachusets, 1924; Bedrock Geology Map of Massachusetts and Rhode Island by B.K. Emerson, 1916; Surficial Geology Map of the Pepperell Quadrangle by Carl Koteff and R.P. Volckmann (open file map-unpublished).

GENERAL SITE CONDITIONS

The site is a nearly flat, well-drained, heavily wooded area. Slopes are extremely flat, generally less than one percent, except locally near the Unkety Brook where they may range from 1 to 3 percent. The vegetation is mostly tall pine trees with moderate underbrush and minor amounts of deciduous trees such as birch and pin oak. A small branch of the Unkety Brook emanates from a swamp area near the middle of the site and drains to the northeast. A transmission line bisects the site west to east as shown on the Locus Plan. A small pond exists in the southwest corner of the site near East Street.

BEDROCK

No bedrock exposures were noted at the site including the lowlying areas adjacent to Unkety Brook. According to B.K. Emerson, the underlying bedrock is part of the gneisses and schists of undetermined age. According to Emerson, the principal types are "biotitic gneiss and schist of undetermined origin" within this general area. The depth to bedrock is not known but judging from the absence of relief and the soil conditions, bedrock is estimated to exist below 20 feet from existing ground surface.

SOILS

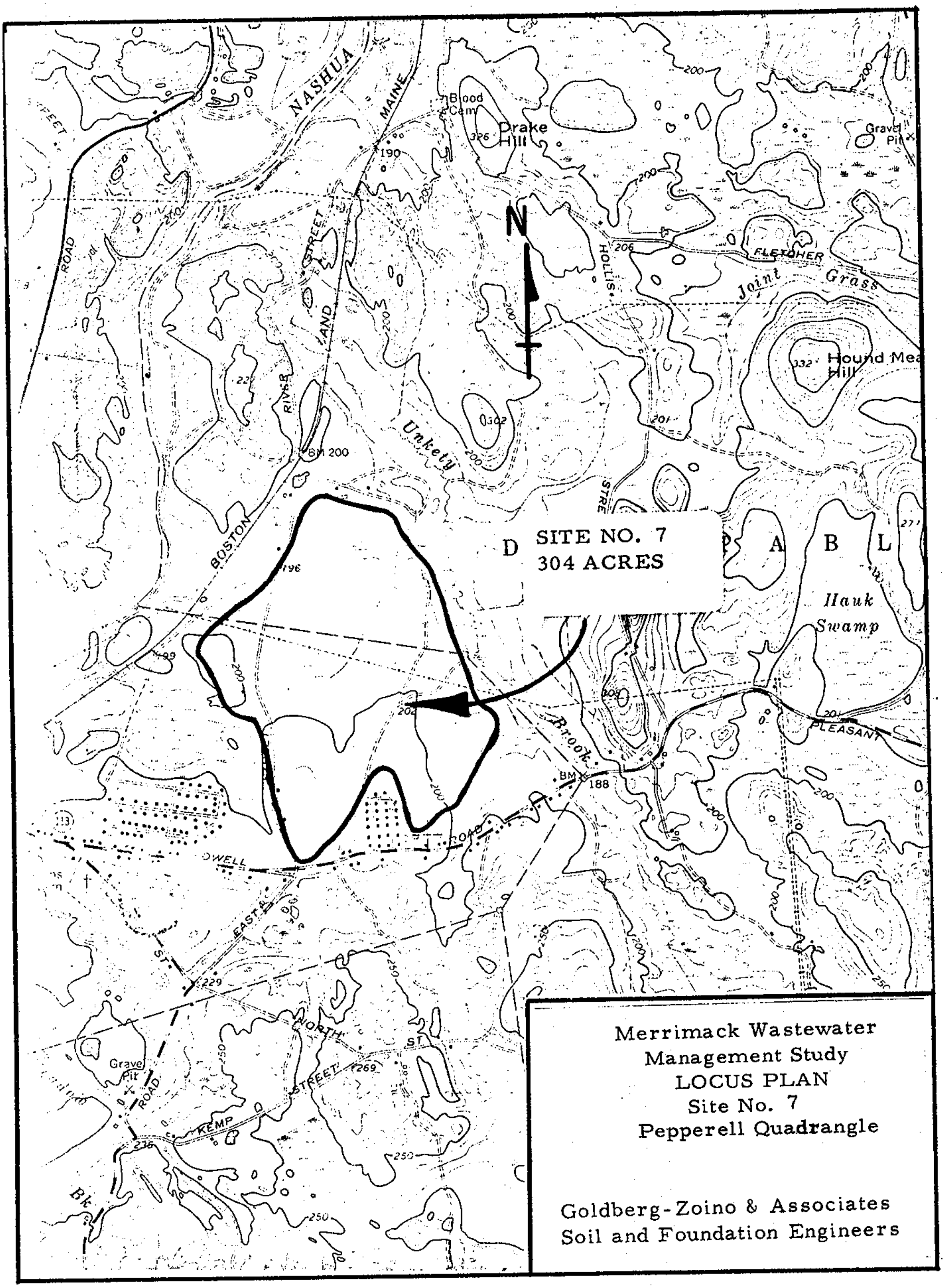
Soil formations at the site are outwash plains associated with the Unkety Brook. There is almost total absence of rock, cobbles, or boulders in the area. Excavations on-site indicate that the material is a light brown, fine to medium sand, little coarse sand, trace silt. The materials appear to be very clean, generally exhibiting less than 5 percent passing the No. 200 U.S. Standard sieve. According to the Soil Conservation Service mapping, the formation is part of the Merrimack sandy loam, which is part of Group 2.

GROUND WATER

Although the soil is well-drained on the surface, nevertheless, the ground water table is believed to be relatively high throughout the area. This ground water table is undoubtedly influenced by the Nashua River located to the west and by Unkety Brook to the east. A small swamp area in the center of the site and a small pond in the southwest corner are indicative of the high ground water table. Generally ground water is expected within 5 feet from existing ground surface.

OVERALL EVALUATION OF SITE

Although soils at the site are highly permeable, the site would probably not be good for rapid infiltration because of the high ground water table. Similarly, the site would also be considered poor for overland runoff because of the relatively high surface permeability of the soils. The site would be rated fair to good for use of spray irrigation. The position of the ground water table would appear to be the controlling factor. This ground water table could best be substantiated by test pits or observation wells on the site to establish the ground water regime before final conclusions could be reached.



Merrimack Wastewater Management Study
LOCUS PLAN
Site No. 7
Pepperell Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTEWATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #8

SITE LOCATION

The site is located in the U.S.G.S. Maynard Quadrangle, bisected by Sudbury Road with the town of Maynard lying northeast of Sudbury Road and the town of Hudson lying southwest of Sudbury Road. Boons Pond lies immediately south and west, while the Assabet River lies just north of the site.

AVAILABLE DATA

Available data include the following: Geology of the Hudson-Maynard Quadrangle, U.S.G.S. Bulletin 1038 Plate 2 by W.R. Hansen, 1956; Bedrock Geology Map for Massachusetts by B.K. Emerson, dated 1917; Middlesex County Soil Survey (U.S.D.A.) dated 1924; and U.S.G.S. Maynard Quadrangle Topographic Map.

GENERAL SITE CONDITIONS

The site encompasses approximately 230 acres. It is flat with less than 10 feet relief over the entire site. The deposits are believed to be a kame plain formed in contact with ice block remnants which formerly occupied abutting lake and swamp. A few shallow scattered kettle holes exist over the site, all of which are shown as local depressions on the U.S.G.S. Quadrangle Map.

The site is almost entirely forested with a predominance of evergreens. Where trees are mature few if any deciduous trees exist, but where trees are younger, small deciduous trees represent about 50 percent of the growth.

Occasional scattered houses exist along Sudbury Road. The largest concentration of private dwellings occurs on the western boundary of the site near Boons Pond. In any case the number of residences should be considered as a very minor factor in the characteristics of the site.

Essentially the entire site is forest. Two types of forest growth exist: the first type is a mature pine forest with little or no deciduous trees; the second consists of younger trees, about half white pine and half deciduous trees. In this latter case, the deciduous trees are primarily oak and maple. As noted above, the site is essentially flat with surface slopes of about 0.5 percent or less.

BEDROCK

No bedrock exposures were observed at the site. Information concerning bedrock was obtained from Emerson (See above cited reference.) This rock is identified as Andover granite, "typically a biotite-muscovite granite of moderately coarse and generally uneven grain."

SOILS

The basis of interpretation of soil condition is the above referenced data plus numerous exposures which were physically examined in the field. These exposures consisted principally of the following:

a. A series of drainage pits approximately 4 feet deep placed at regular intervals along the roadway which runs transverse to Sudbury Road and leads to Boons Pond.

b. Sides of kettle holes.

c. A large zone where topsoil and subsoil were stripped on the eastern boundary of the site adjacent to the Natick Laboratories.

d. A small borrow pit near the northern site boundary.

These above data revealed a consistent pattern of soil conditions: namely, a very clean fine to coarse sand containing little to some fine gravel and having a slight trace of silt. These soils are extremely pervious and therefore free-draining. The County Soil Survey describes this soil as a Merrimack loamy sand, characterized by about 6 to 8 inches of topsoil and with yellowish subsoil containing some gravel to a depth of about 15 inches.

Ground water is controlled north of the site by the Assabet River (about elevation 200) and south and west of the site by Boons Pond (about elevation 186). Kettle holes were examined in the field for presence or absenceof ground water. On the basis of these data it is inferred that ground water depth ranges from approximately 8 to 12 feet except near Boons Pond where the depth may be 15 feet or more.

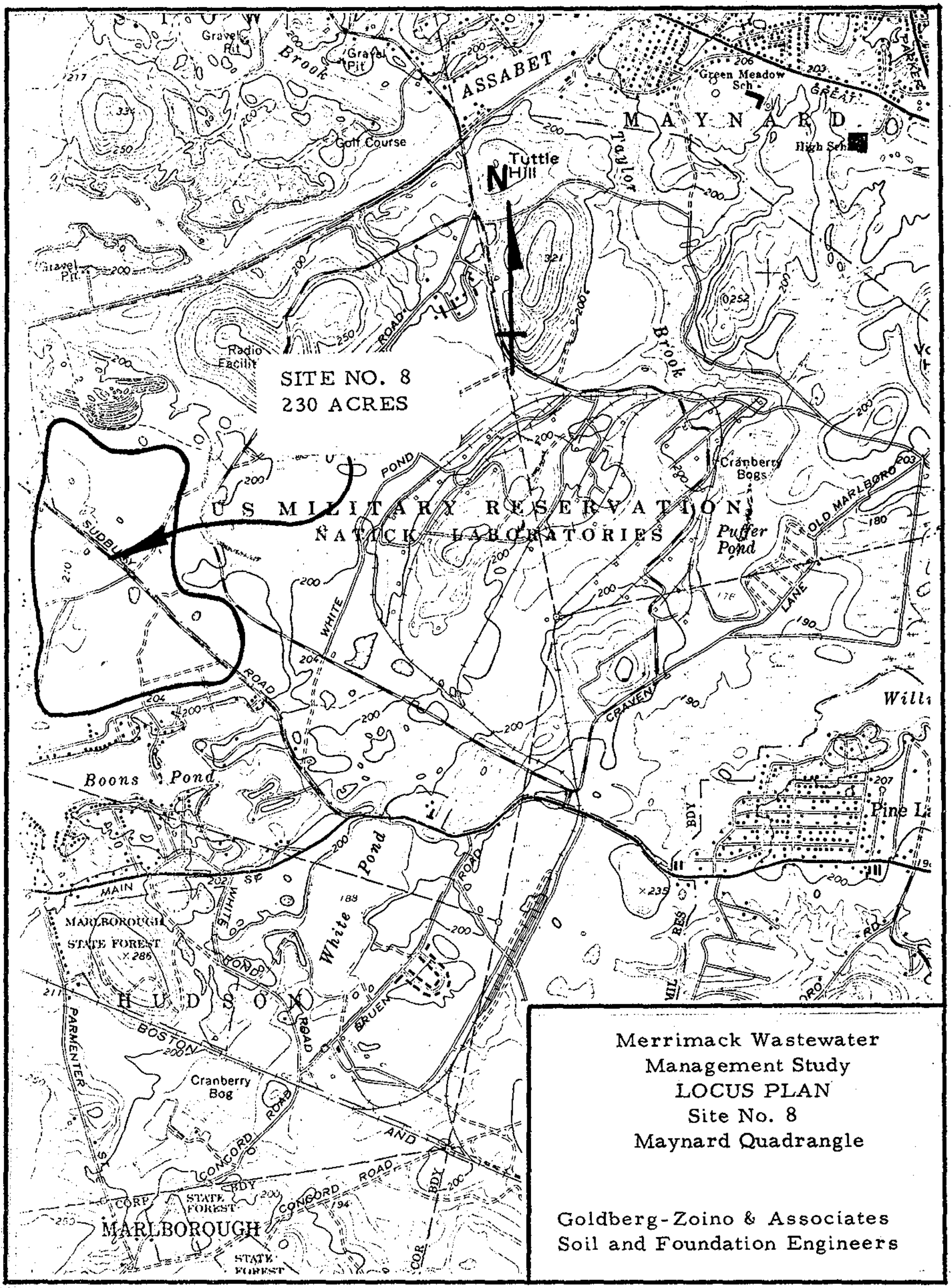
OVERALL EVALUATION OF THE SITE

The controlling features of the site are the highly pervious glacial outwash plain, the generally flat topography and the ground water depth estimated at depths of 8 to 15 feet. Accordingly the ratings for wastewater treatment are:

Rapid Infiltration	fair/good
Spray Irrigation	good
Overland Runoff	poor

The highly pervious soils may govern the rate of application for spray irrigation.

Soils appear to be sufficiently pervious for rapid infiltration but depth to water table is marginal.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 8
Maynard Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTE WATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #9

SITE LOCATION

The site is located north of Route 20 about one mile east of the town of Marlboro. It is located in the U.S.G.S. Marlboro Quadrangle.

AVAILABLE DATA

Data consist of Middlesex County Soil Survey (U.S. Department of Agriculture) date 1924; Map in Physical Features of Massachusetts, U.S.G.S. Bulletin No. 760, Plate 6 by Alden and Emerson, dated 1924; (It should be noted that the Marlboro Quadrangle has not been mapped in detail by the Geological Survey;) U.S.G.S. Marlboro Quadrangle Topographic Map; and the Bedrock Geology Map for Massachusetts prepared by B.K. Emerson, dated 1917.

GENERAL SITE CONDITIONS

This site encompasses approximately 430 acres. Visual examination indicates about 75 percent of the area is wooded, consisting primarily of deciduous trees (predominantly oak and maple) with few scattered white pine. Few surface boulders were noted within the wooded areas but many stone walls were in evidence, an indication that the area was probably formerly under cultivation.

Non-wooded areas include the following:

a. An abandoned orchard (about 20 acres) on top of Spoon Hill.

b. A large apple orchard and stables on the northerly portion of Stowe Road where it borders the site.

c. Relatively new housing developments (typically less than one to two years old) along the northerly half of Hosmer Street and to about 1/4 mile east toward Spoon Hill.

Predominant growth in the forest are deciduous trees with few scattered evergreens. Typically the deciduous trees are hardwoods with most trunks 6 inches to 12 inches in diameter. The abandoned orchard contains little or no tree growth other than old apple trees, small bushes, and young trees less than about 5 feet high.

Topography is steep. The steepest condition exists in the rock and largely bedrock exposed slope just north of Spoon Hill Avenue where slopes are estimated to be 20 to 25 percent. Slopes on the east and west side of Spoon Hill are typically about 10 to 15 percent while most of the remaining area has slopes ranging from about 6 to 9 percent.

BEDROCK

Bedrock is mapped as Andover granite on the Emerson Bedrock Geology Map for Massachusetts. Many observations of this granite were made at scattered locations over the entire site. Emerson describes the Andover granite as "typically a biotite-muscovite granite of moderately coarse **and** generally uneven grain."

SOILS

A glacial till ground terrain covers an estimated 90 percent of the site. The remaining area consists of glacio-fluvial deposits in the extreme northern portion of the site below approximately elevation 270. A very large exposure of glacial till was noted on top of Spoon Hill where the topsoil had been stripped and stockpiled. Visual classification of this till is a well-graded sand and gravel, containing an estimated 30 percent non-plastic silt, and with cobbles and boulders typically to about 12 inch size. It should be noted that the referenced County Soil Survey maps this soil as Charlton loam, typically with 24 to 30 inches of topsoil and subsoil over the till. Other common soil types shown on the County Soil Survey Map are Charlton stony loam and Charlton stony fine sandy loam, all at lower elevations. In general, the glacial tills within the Charlton series are quite similar.

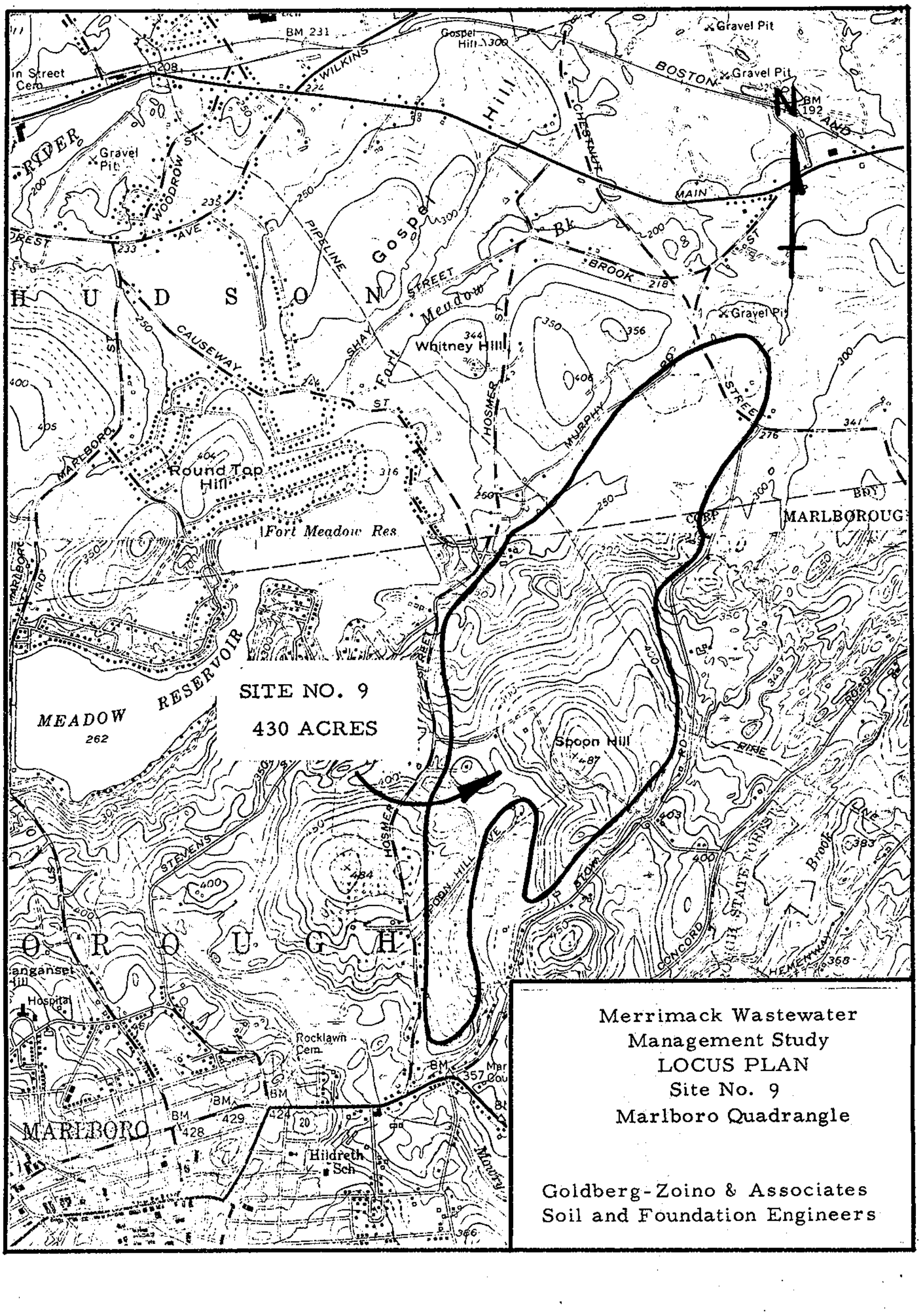
Glacio-fluvial deposits in the extreme northern portion of the site were observed in a large excavation made to a depth of about 5 feet for a housing project currently under construction in that area. This soil was a relatively uniform fine sand containing an estimated 20 percent silt. An abandoned borrow pit about 1 mile north of the site revealed relatively silty stratified sand and gravel.

The County Soils Survey Map also shows meadows lying in the lowland between the hills. The largest of these is west of Spoon Hill and consists of about 20 acres of cleared land. There is limited evidence to suggest that relatively free draining granular soils may exist on the flank of this meadow up against the slopes of the rising hills.

Ground water in the glacial till terrain will be controlled largely by the slope of the land and also by the depth of the underlying bedrock. Typically it is anticipated that ground water depth will range between less than 5 feet to about 10 feet and also that fluctuations will occur with seasons.

OVERALL EVALUATION OF SITE

The controlling features of the site with respect to use for waste water treatment are the presence of glacial till over shallow bedrock with high ground water table and variable steep slopes frequently greater than 8 percent. Consequently soil types preclude both rapid infiltration and spray irrigation. Soils are suitable for overland runoff but steep slopes pose difficulties.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 9
Marlboro Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTEWATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #10

SITE LOCATION

Site #10 is located adjacent to the Nashua River partially in the Town of Bolton and partially in the Town of Lancaster, Massachusetts. The site is bounded by the Nashua River on the south and east and by the Boston & Maine Railroad on the north and the west. Access to the site is on Pine Hill Road, adjacent to the Fort Devens Military Reservation. The site area encompasses some 215 acres as shown on the locus plan.

AVAILABLE DATA

Data which were reviewed prior to our site visit consisted of the USGS Clinton Quadrangle Map and also the Surficial Geologic Map of the Clinton Quadrangle Worcester County, Massachusetts (Map GQ-567). The general bedrock geology map of Massachusetts at a scale of 1:250,000 prepared by B. K. Emerson was also consulted in terms of bedrock types in the vicinity.

GENERAL SITE DESCRIPTION

The site is essentially an elongated flat topped terrace adjacent to the Nashua River and one of the minor tributaries of the Merrimack River. The access to the site is on Pine Hill Road which enters into a rather extensive sand and gravel pit occurring at the southwest corner of the site. The Boston & Maine Railroad forms a boundary and as one travels the service road adjacent to the railroad, the rather extensive small arms firing ranges of the Fort Devens Military Reservation are clearly visible. Portions of the area have been cleared of trees in the past and some light scanty growth has in recent years replaced some of the cleared areas. It may be described in general terms as flat, moderately to lightly wooded and densely wooded in very limited areas. The flat lying surface of the terrace drops rather steeply on all sides to the Nashua River Flood Plain and to another separate tributary flood plain located to the north and west. Surface features show no exposures of bedrock but sand and fine gravel are in evidence throughout the entire area.

BEDROCK

No bedrock exposures were visible on the site during our examination on September 18, 1973. A survey was made along the river bank of the Nashua River in the southeast portion of the site and no bedrock exposures were noted. However, a bedrock exposure was noted about 1500 feet southwest of the site just south of the intersection of Pine Hill Road and Harvard Road. This bedrock exposure consists of a hard slaty rock. According to the geological mapping of B.K. Emerson in 1916, this slaty rock is a younger carboniferous formation known as the Worcester Phyllite. In general "in its least changed or typical phase the Worcester Phyllite ranges from soft black slate or phyllite, partly carbonaceous and partly graphitic to light greasy sericite schist." A hand specimen obtained in this location shows the rock to be of slaty characteristics having a parallel arrangement of minerals with a flaky habit.

The elevation of the bedrock occurring southwest of the site is at or near the elevation of the terrace deposit forming the site. However, the depth to bedrock at the site is not actually known. Based on absence of outcrops along the river banks, it is probable that bedrock occurs at depths greater than 40 feet at the site. However, a final determination of bedrock depth would have to be made by test borings or using geophysical methods.

SOILS

Soil conditions at the site are well exposed in cross-section in the southwest portion where the gravel pit operation is being conducted. In one bench of the gravel operation a 20 ft. high vertical exposure was noted. This formation could be described as a gray to brown well-graded fine to coarse sand and fine gravel. Visual examination indicates less than 5% silt size (material passing a U.S. Standard No. 200 sieve). The sand grains appear to be subrounded in shape and consist mostly of quartz, feldspar and minor amounts of mica. The coarser fragments, particularly in the gravel sizes have a higher percentage of schist and slaty pieces than the finer fraction. However, slaty particles appear to make-up less than 5% of the total volume of the material. The maximum size of the gravel was in the order of 3 inches.

The vertical and sloping exposures indicated a general stratification consisting of nearly horizontal layers of sand from 6 to 18 inches thick interspersed with layers of fine gravel exposures 6 to 12 inches thick. Some portions of the area had been stripped of topsoil and subsoil. However some remaining exposures indicated that the topsoil is quite sandy, generally less than 6 inches thick and the subsoil consists of fine sand and silt, generally less than 2 feet thick.

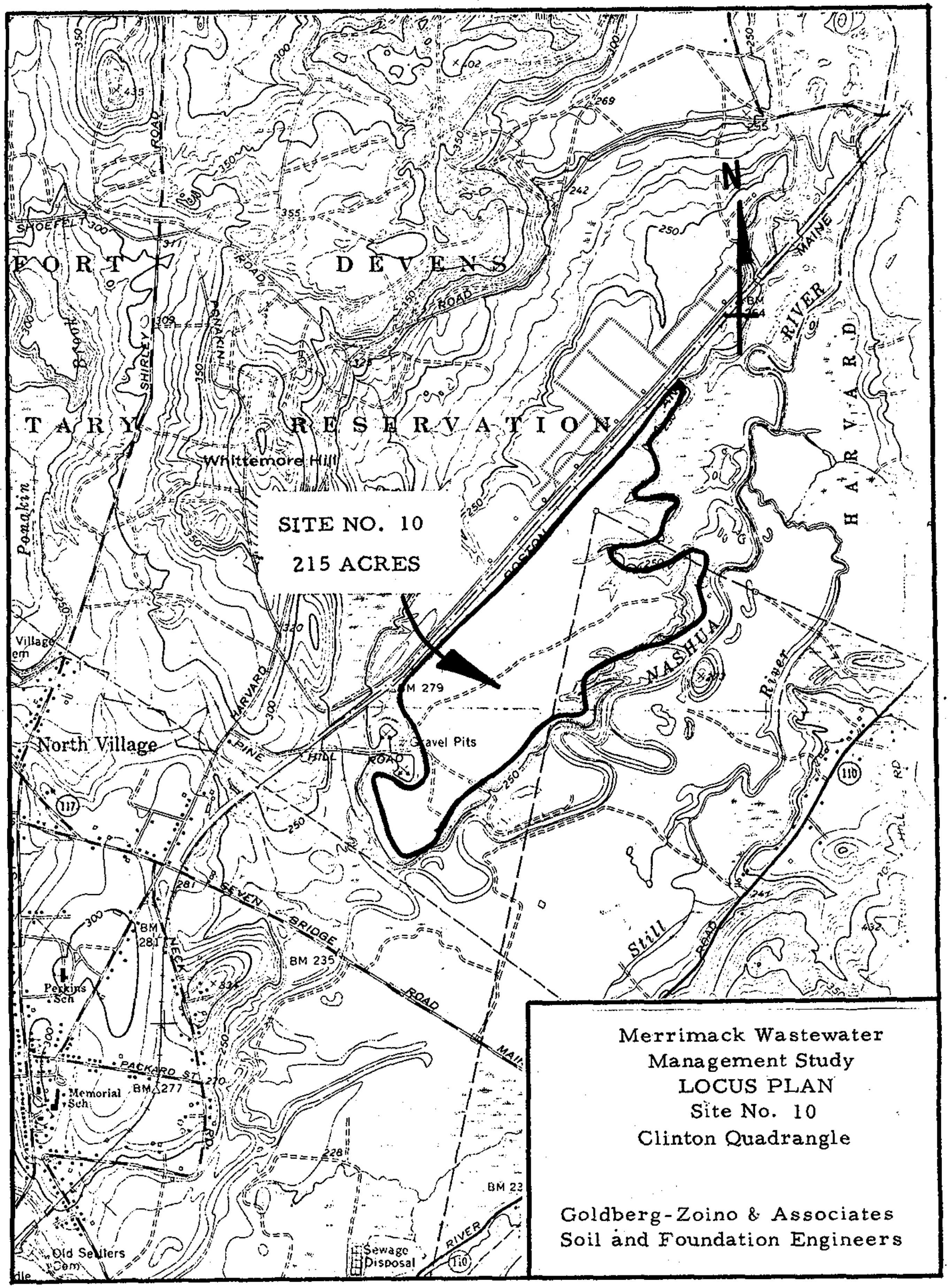
According to the surficial geologic map of the Clinton Quadrangle prepared by Carl Koteff in 1966, the above described formation is a part of the Glacial Lake Nashua Deposits and in particular the Ayer Stage Deposits (Qna) which consist of sand and pebble gravels. According to Koteff, these Ayer Stage Deposits may be over 30 feet thick and overlie fore-set beds of fine sand and medium sand and a few thin clay layers. The Soil Conservation Service Maps indicated these soils to be Hinckley loamy sand and Merrimack loamy coarse sand.

GROUNDWATER

Based on topographical and geological evidence, it is estimated that groundwater is generally 40 feet or more in depth or slightly higher than the Nashua River. A final determination of groundwater depth would involve installation and monitoring of observation wells throughout the site.

EVALUATION OF SITE

Based on our visual examination of the site we have concluded that the deposits underlying the site are of a generally high permeability. It would be expected that the coefficient of horizontal permeability would be an order of magnitude greater than the coefficient of vertical permeability because of the nearly horizontal stratification. In general, it is expected that this site would be rated good to excellent in terms of its suitability for disposal of effluent from sanitary treatment of wastewaters. In particular, it may be well suited for rapid infiltration. However, before any final conclusions could be reached on this site, detailed engineering would have to be undertaken which would include test borings, field permeability tests, and other engineering evaluations before the magnitude and results of wastewater treatment at this site could be assessed.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 10
Clinton Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTEWATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #11

SITE LOCATION

The site is located within the Towns of Lancaster and Sterling, Massachusetts. The site is bounded on the east by George Hill Road, on the north by Hill Top Road, on the west by Albright Road and on the south by Sterling Road and the New York, New Haven & Hartford Railroad. The site area comprises some 450 acres which is generally heavily wooded except along the roads where extensive residential construction has occurred during the last decade.

AVAILABLE DATA

The data available for our use prior to the on-site inspection consisted of the U.S.G.S. Clinton Quadrangle Sheet, the surficial Geologic Map of the Clinton Quadrangle (map GQ 567) and the bedrock geology map (scale 1:250,000) for the State of Massachusetts prepared by B.K. Emerson.

GENERAL SITE DESCRIPTION

The site is essentially a large hill which slopes to the previously described roads on all sides. Slopes vary from 3 percent to 12 percent. Minor swampy areas of limited extent were also noted particularly along Hill Top Road on the north and in the area adjacent to the New York, New Haven, & Hartford Railroad in the southern and eastern portions of the site. Because of the relief at the site (approx. 130 feet) and the subsurface conditions, a relatively high coefficient of runoff is evident.

BEDROCK

Several exposures of bedrock were noted in the road cuts along Hill Top Road in the northern portion of the site, and along George Hill Road in the eastern portion of the site. Although the number of outcrops visible along the roadway were somewhat limited there is considerable evidence of shallow bedrock throughout the entire area.

A large number of stone fences constructed of slaty rock are visible in the area and there are angular slaty rock fragments incorporated within the soil exposures around the site. The bedrock is part of the Worcester Phyllite as shown on the geological map of Massachusetts and Rhode Island by B.K. Emerson. According to Emerson: "in its least changed or typical phase the Worcester Phyllite ranges from soft black slate or phyllite, partly carbonaceous, and partly graphitic, to light greasy sericite schist.". In general, the evidence on the site would indicate the bedrock is quite shallow and would be anticipated within depths of 0 to 10 feet below presently existing ground surface.

SOILS

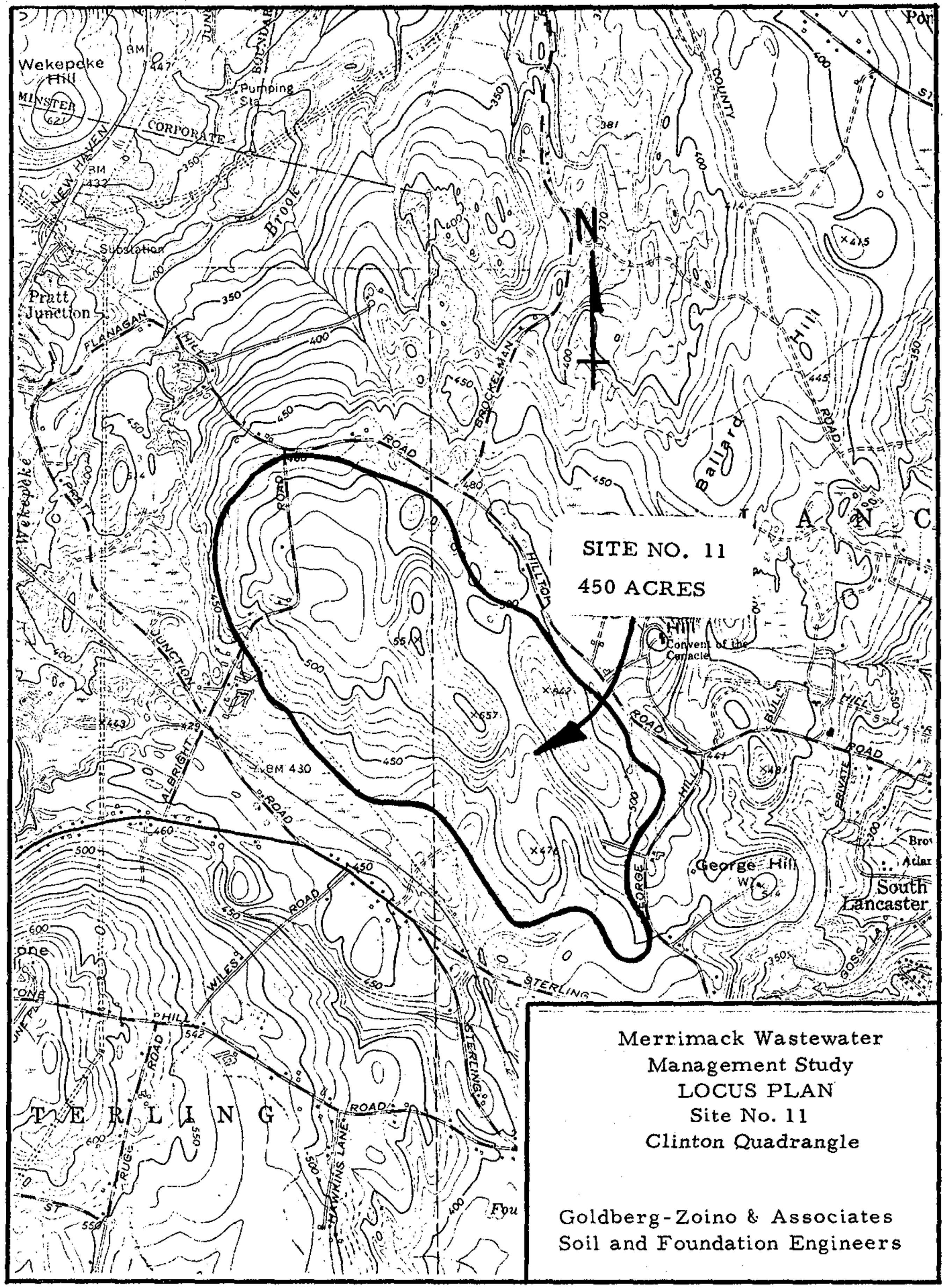
The soil formations noted at the site consist of a brown silt and fine sand with boulders generally not exceeding 18 inches in size. The finer fraction of the formation contains a small percentage of clay and the material exhibits a slight plasticity when it becomes wet. In many of the soil exposures, the coarse fragments consist of dark gray angular gravel size fragments of slate (phyllite) interspersed throughout the soil formation. According to the surficial geologic mapping by Koteff, the soil is a glacial till consisting of a poorly sorted unstratified mixture of silt, sand, gravel, and boulders with minor amounts of clay. The Soil Conservation Service classification is Bernardston silt loam and Bernardston silt loam stony phase. These are included in soil group 3.

GROUNDWATER

The position of the groundwater table would have to be determined by observation wells throughout the area. It is estimated that groundwater would be found generally at depths of 2 to 10 feet below ground surface because of bedrock and soil conditions. This would be expected to vary throughout the year in accordance with seasonal phenomenon.

EVALUATION OF SITE

Based on the available data and the site examination, it was our impression that the site would have very limited value for treating wastewater from the Merrimack River Watershed. It is believed that the site would have no value for rapid infiltration (because of low permeability soils and shallow bedrock) and would have very limited value in terms of spray irrigation, or overland flow (because of steep slopes). It is also limited by the fact that the site is primarily a residential area with single family homes closely located along the roads which surround the site.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 11
Clinton Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTEWATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #12

SITE LOCATION

The site is located partially in the town of Salisbury, Massachusetts and partially in the town of Amesbury, Massachusetts. It is bounded by Munroe Street to the south, Main Street to the southeast, Congress Street to the north, and Mundy Hill to the West. The Amesbury Country Club, a nine-hole golf course, occurs in the southern portion of the area.

AVAILABLE DATA

Information available of a published nature prior to our site visit included the U.S.G.S. Newburyport West Quadrangle Map, the Essex County Soil Survey (U.S. Department of Agriculture Soil Conservation Services) and the Bedrock Geology Map for Massachusetts prepared by B.K. Emerson in 1917.

GENERAL SITE CONDITIONS

The site encompasses approximately 387 acres as shown on the locus plan. Approximately 50 percent of the site is open or grassy area, including farm areas, and approximately 50 percent of the site is wooded. The topography is a mixture of moderately steep, sloping terrain with slopes of 15 to 20 percent such as on the flanks of Mundy Hill and the Amesbury Country Club, and somewhat flatter slopes generally less than 8 percent, particularly in the eastern half of the site and below elevation 100. There is a rather dramatic change in zoning use between Amesbury and Salisbury. That is the portion of the site located in Amesbury seems to have a residential character whereas the eastern half of the site in Salisbury is more of a rural or farming character. Bedrock exposures are not clearly visible except in the lowlying area along Mingo Road in the eastern portion of the site.

BEDROCK

The bedrock underlying the site is the Newburyport Quartz Diorite. This formation can be seen in an exposure along Mingo Road where it appears as a hard, competent, medium to fine-grained crystalline rock.

According to Emerson, it is a "light gray, medium-grained, granular rock containing orthoclase, labradorite, augite, hornblende, and quartz, with clorite, uralite, and epidote as decomposition products."

The bedrock exposures generally occur between elevations 50 to 60 in the eastern portion of the site. However, the depth to bedrock below Mundy Hill (maximum elevation 193) is not known and can only be determined by test borings or other explorations at the site.

SOILS

According to the Soil Conservation Service maps of Essex County, the principal soil types are (1) the Woodbridge loam occuring above elevation 100, (2) the Merrimack sandy loam between elevation 60 and 100, and both (3) Meadow soils and (4) Hinckley gravelly sandy loam in the lowlying areas. A grain-size distribution curve for the Woodbridge loam was made at another site in Amesbury approximately two miles to the west of the site. This grain-size distribution curve shows the following:

U.S. Standard Sieve	Percent Finer
1/2 inch	90
No. 4	82
No. 10	75
No. 20	68
No. 40	60
No. 60	52
No. 100	45
No. 200	33

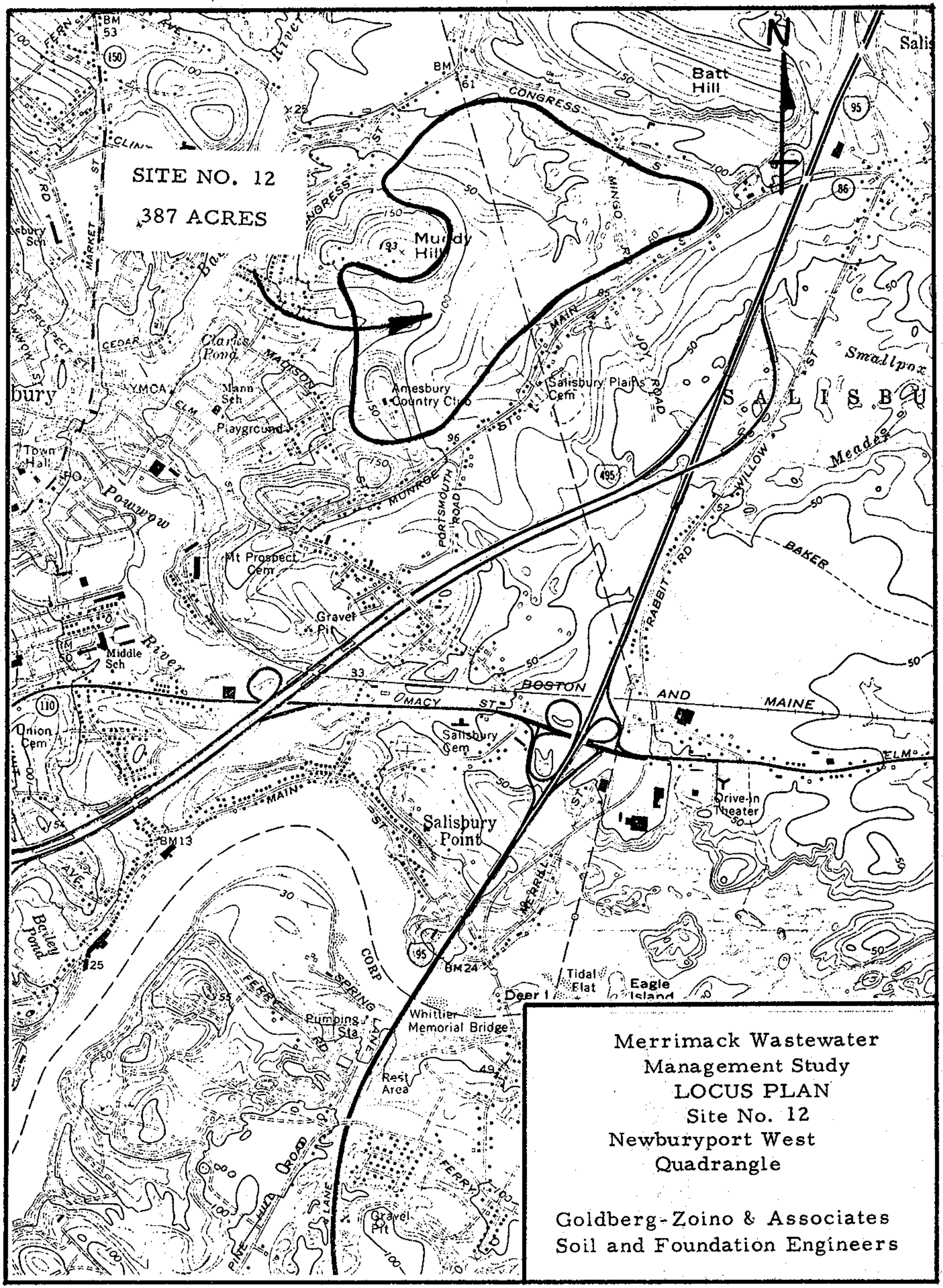
The permeability of the soil formations is expected to be on the low side but because of the variations in slope and soil types at the site, field testing would be necessary to verify the coefficient of permeability of the various soil formations.

GROUND WATER

Ground water was observed at or below elevation 30 to elevation 70 in the lowlying areas and would be expected to vary throughout the site in accordance with the topography and soil conditions. Generally speaking, it is estimated that the ground water table would occur at depths of 0 to 10 feet from presently existing ground surface.

OVERALL EVALUATION OF THE SITE

The suitability of the site for wastewater treatment is difficult to assess on the basis of the information outlined above. However, because of the low permeability of the soils and the high ground water conditions, as well as the probable shallow depth to bedrock in the lowlying areas, we would rate the site as poor in terms of its use for rapid infiltration. The site may be suitable either wholly or in part for both spray irrigation or overland run-off methods of wastewater treatment. Our initial impression is that the site would be fair in these areas because of slopes and partial absence of vegetation. However, this would have to be verified by detailed on-site explorations before any final assessments could be made.



Merrimack Wastewater Management Study
LOCUS PLAN
Site No. 12
Newburyport West Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTEWATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #13

SITE LOCATION

The site is located within the town of Newburyport, Massachusetts. It is bounded by the Merrimack River on the north and west and by Mill Road and Pine Hill Road on the south and east respectively. A locus map showing the location and site boundaries is included herewith.

AVAILABLE DATA

Prior to an on-site visit, several sources of information were checked to develop preliminary ideas of the nature of the site. The data consulted consisted of (1) the U.S. Geological Survey Newburyport West Quadrangle, (2), the U.S. Department of Agriculture Soil Conservation Service Soil Map for Essex County, (3) the Bedrock Geology Map for the States of Massachusetts and Rhode Island (scale 1:250,000) by B.K. Emerson and (4) Geologic Map of the Coastal Areas from Hampton Beach, New Hampshire to Squam River, Gloucester, Massachusetts, prepared by N.E. Chute and R.L. Nichols in 1940.

GENERAL SITE DESCRIPTION

The site consists essentially of somewhat knobby or hummocky terrain and also contains well-drained, gentle to flat slopes. Certain portions of the site, particularly on the edges of the small hills and along the edge of the Merrimack River, have steeper slopes which approach a maximum of 20 to 25 percent. However, these steep slopes are confined to limited areas of the site and the site, for the most part, has slopes generally less than 8 percent.

The total site area encompasses approximately 366 acres. The area is moderately wooded with approximately one-third being open area and corn fields. A major portion of the site consists of the Mosely Estate which has extensive areas of rhododendrons, scenic trails, and stone masonry bridges across minor streams, particularly in the southwestern portion of the site. This area has a very high aesthetic value because of its natural beauty and its setting in relationship to the Merrimack River.

A small brook flows from southeast to northwest in the western part of the site. This brook, which may be spring-fed, enters a small man-made pond and then discharges into the Merrimack River.

BEDROCK

No bedrock outcrops were visible during our site visit. However, according to Newton Chute, there may be some outcrops visible in the southwest corner of the site and in the northern extremity which is a small area underlain by glacial till. The bedrock in this area is believed to be the Dedham granodiorite. According to B.K. Emerson, "the most abundant and typical variety is a rather coarse biotitic granodiorite, composed essentially of microcline, plagioclase (generally andesine), quartz, and chlorite, and commonly more or less epidote and kaolin". While the depth to bedrock may be shallow in the southwest corner of the site and the northern extremity of the site, it is believed that bedrock is generally of the order of 30 feet or more in depth throughout the major portion of the site. This assessment is based on very rough and limited information and would have to be verified by on-site explorations including further geological reconnaissance, geophysical explorations, and test borings.

SOILS

The soils existing at the site have been mapped by Newton Chute as kames. Generally speaking, this would indicate sandy or gravelly formations with varying degrees of stratification and a relatively high coefficient of permeability. A limited area in the southeast portion of the site and the northern portion of the site consists of glacial till with shallow bedrock.

The Essex County Soil Conservation Service Survey indicates soil types in the approximate quantities as follows:

SOIL SYMBOL	NAME	PERCENTAGE
M_c	Merrimack Loamy Sand	45%
H_s	Hinckley Loamy Sand	30%
M_s	Merrimack Sandy Loam	15%
W_o	Woodbridge Loam	10%

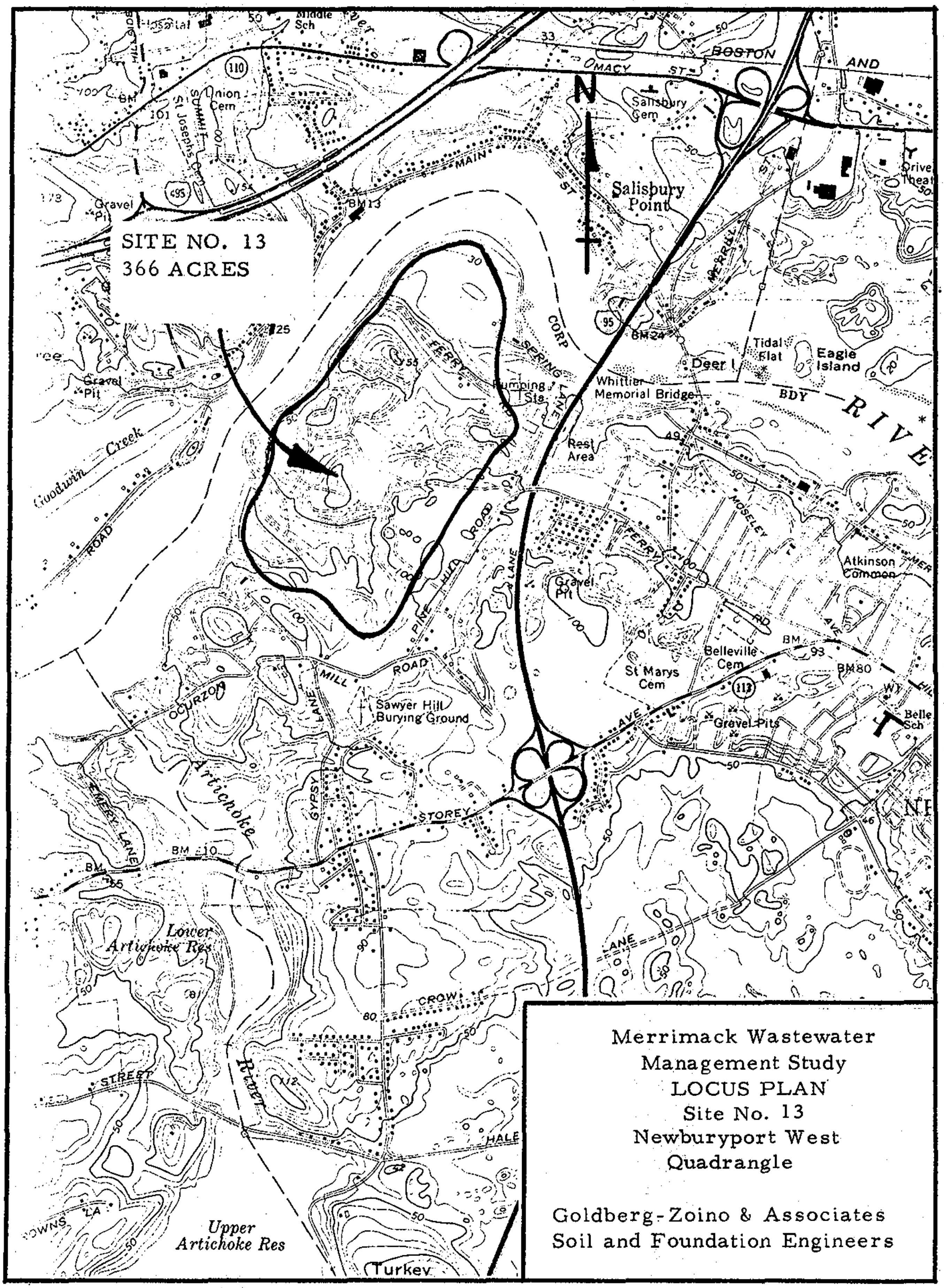
With the exception of the Woodbridge loam, which would be expected to have low permeability, the remaining soils encompassing some 90 percent of the site would be considered within soil group 2. These have been described as: "deep, droughty, rapidly permeable, glacial outwash loamy sands, which may contain gravel in the subsoils".

GROUND WATER

Ground water table throughout the site is believed to be influenced strongly by the elevation of the Merrimack River and in addition by the layer of glacial till which may serve as an impervious barrier particularly in the southern portion of the site. The ground water table may slope from east to west in a fashion similar to the brook which flows towards the Merrimack River. However, a number of ground water observation wells would be required at the site to evaluate this with any accuracy.

OVERALL EVALUATION OF SITE

Based on the available information, the site would appear to be very suitable for wastewater treatment, particularly spray irrigation or rapid infiltration. The depth to bedrock and the position of the ground water table may tend to rule out the rapid infiltration possibility. Detailed on-site explorations would be required before any final conclusion regarding site suitability for wastwater treatment could be ascertained. In all probability, however, the site would not be suitable for overland run-off methods because of the relatively permeable nature of the soils.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 13
Newburyport West
Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTEWATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #14

SITE LOCATION

The site is located in the Town of West Newburyport, Massachusetts adjacent to the site of the Cardinal Cushing Academy. The site is bounded by River Road (adjacent to the Merrimack River) on the north, by Route 113 on the south, by Coffin Road on the east, and by Long Hill and Baileys Hill Road on the west. The site encompasses some 670 acres as shown on the accompanying locus plan.

AVAILABLE DATA

The data consulted prior to our site inspection consisted of: 1) U.S.G.S. Newburyport West Quadrangle, 2) U.S. Department of Agriculture Soil Conservation Service Soil Map of Essex County, Massachusetts, 3) Bedrock Geology Map of Massachusetts and Rhode Island prepared by B.K. Emerson, and, 4) a soil Engineering report prepared in 1972 by Goldberg-Zoino & Associates, Inc. on the adjacent parcel (to the east), being the present site of the Cardinal Cushing Academy.

GENERAL SITE CONDITIONS

The most prominent feature of the site is Long Hill which covers a high percentage of the area and dominates the flanking low lying terrain. Long Hill contains rather extensive apple orchards which at the time of our visit were at the peak of their productivity. Approximately 60% of the site is moderately to densely wooded and 40% of the site is open area and farm land including the apple orchards. Slopes throughout the site are variable, ranging from a maximum of 20 to 25% on the western edge of Long Hill, and generally from 3 to 7% in many areas of the abutting terrain along Long Hill. Bedrock outcrops are well exposed, particularly along the River Road which abuts the Merrimack River.

BEDROCK

According to B.K. Emerson, the bedrock at the site is a portion of the Merrimack Quartzite which contains actinolitic quartzite, dark phyllite, and slate. A hand specimen obtained from an outcrop along River Road indicates a closely foliated, slaty rock somewhat similar in appearance to the Worcester Phyllite except that it has a wavy surface along the individual thin bedding plains. Soil formations encountered both on Long Hill and the abutting terrain show similar evidence of slaty rock fragments within the soil formations. Consequently, it is inferred that bedrock is shallow throughout the area and probably does not exceed depths of 20 feet. This estimate would have to be verified by test borings or geophysical methods for a more definitive conclusion. According to test pits excavated at the adjacent site, bedrock was not generally encountered to depths of 12 to 14 feet below existing ground surface. Therefore, the estimate of 20 foot depth to bedrock considers this data, as well as the outcrops noted along River Road.

SOILS

Soil formation as shown on the Soil Map of Essex County prepared by the Soil Conservation Service appear to be present in the following approximate quantities:

Symbol	Name	Soil Group	Approx. Percent
Wo	Woodbridge loam	3	25
Cl	Charlton loam	5	25
Hf	Hollis fine sandy loam	6	15
Hs	Hinckley loamy sand	2	15
Mc	Merrimack loamy sand	2	20

The material in the area identified as Woodbridge loam occurring at Long Hill may be described as a light brown silt and fine sand, with some angular gravel fragments. A grain size analysis made on this material at the abutting site indicates the following:

U.S. Sieve Size	Percentage Finer by Weight
1"	93%
No. 4	83%
No. 10	79%
No. 20	73%
No. 40	65%
No. 60	57%
No. 100	48%
No. 200	38%

The material in the area identified as Hollis fine sandy loam was also tested on the abutting site. The grain size analysis yielded the following results:

U.S. Sieve Size	Percentage Finer by Weight
2"	95%
½"	85%
No. 4	73%
No. 10	66%
No. 20	59%
No. 40	51%
No. 100	35%
No. 200	23%

According to the soil groupings of the Soil Conservation Service used for this project, it can be inferred that most of the soils are of low to moderate permeability, with the exception of the Hinckley and Merrimack sands which comprise about 35 percent of the area, particularly in the eastern portion of the site along Coffin Road.

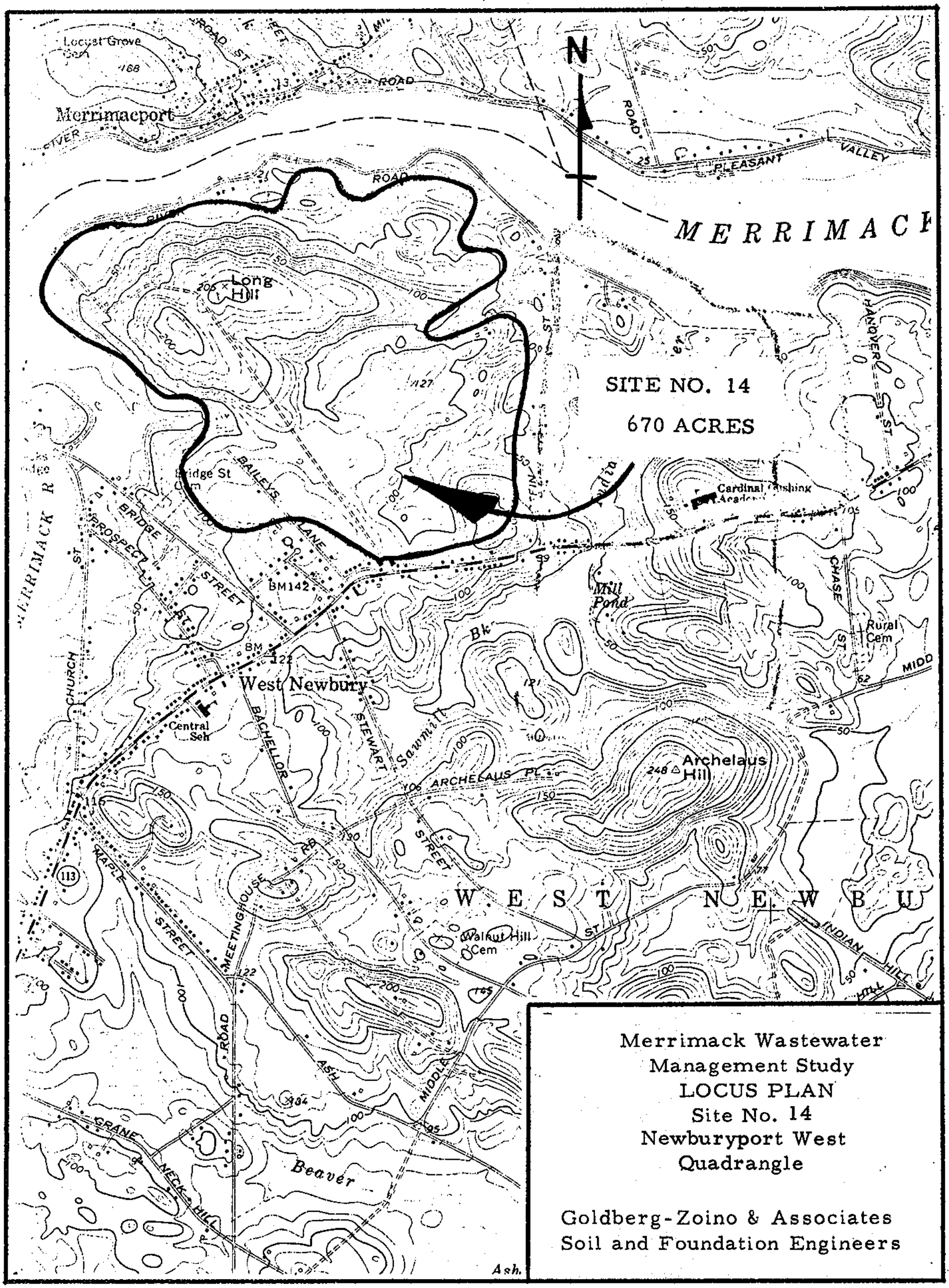
GROUNDWATER

Groundwater was observed in the form of springs flowing from west to east on the eastern flank of Long Hill. According to data from the adjacent site, depth to groundwater is variable ranging from 3 feet to 14 feet in depth. Therefore, a thorough study of groundwater conditions using results of readings from groundwater observation wells would be necessary before any final assessments could be made. However, based on the limited information available, it appears that groundwater might occur at depths of 3 to 20 feet below existing ground surface.

OVERALL EVALUATION OF SITE

Based on the available information, it would appear that the site has poor to fair potential for use in treating wastewater. For example, the site would not be considered good for rapid infiltration because of soil characteristics, steep slopes, depth to bedrock, and probable shallow depths to groundwater.

The site would also be considered poor for use of overland runoff methods because of steep slopes where the soil is relatively impervious, and flat slopes in the area where the soil is relatively pervious. A portion of the site may be suitable for spray irrigation, however bedrock outcrops were noted in this area along River Road and the degree to which it could be used may be limited. In general, our rating from fair to poor does not preclude the possibility that certain portions of the site may be suitable for spray irrigation. Detailed on-site studies would be required to assess this possibility in any conclusive way.



Merrimack Wastewater Management Study
LOCUS PLAN
Site No. 14
Newburyport West Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTEWATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #15

SITE LOCATION

Most of the site is located in the Town of Boxford; a small portion is within the North Andover Corporate limits. The site is bounded to the east by Main Street, to the west by Bradford Street, to the north by the Haverhill Town line and to the south by Pond Street and Lake Shore Road. A transmission line crosses the study area in a northwest to southeast direction, and a secondary street, Barker Road, crosses in the opposite direction. The site encompasses some 686 acres of woodlands and farms. Recent residential construction is underway along Lake Shore Road and Bradford Street, and a golf course exists near the junction of Main Street and Barker Road.

AVAILABLE DATA

The data available for use prior to the on-site inspection consisted of the U.S.G.S. South Groveland Quadrangle Map, U.S. Dept. of Agriculture Soils Map for Essex County (1925), B.K. Emerson's Bedrock Map of Massachusetts and Clapp's Geology of the Igneous Rocks of Essex County, (Scale - 1:250,000).

GENERAL SITE DESCRIPTION

The site is in hilly terrain. Parts of five sizeable hills comprise the majority of the area studied; three are named - Mt. Hayman, Austin Hill and Byers Hill. These hills rise some 200 feet from a base at Elevations 100 to 120 feet. Lowlands to the east and west of the site limits are occupied by swamps. Saddles between the hills occur between Elevations of 150 and 200 feet. Thus the overall appearance is that of rather sharply contrasting relief.

BEDROCK

Several questionable bedrock exposures were seen along Lake Shore Drive near its crossing with the transmission line. They were located in an area where numerous boulders occur, and therefore their identification as bedrock outcrops remains in doubt. They were comprised of a gray colored, medium-grained foliated granite gneiss. However, several of the embedded boulders, as well as cobbles among the nearby stone fences were also comprised of this rock type. Emerson reports gneiss (of indeterminate age) and the Andover Granite as bedrock types native to this vicinity. The rock seen here could qualify as either type inasmuch as the Andover Granite is described as a gray, fine to medium grained, biotite-muscovite granite, more or less foliated and in places strongly gneissic.

The rock occurred at or near Elevation 200 and where seen, soil occurred 15 to 20 feet above this elevation. If, as expected, the land forms in this region are drumlins, a bedrock depth of 15 to 20 feet or more could be predicted. However, these depths need verification via exploratory methods.

SOILS

The dominant soil type present at the site is a dense, fine to coarse sand and gravel with cobbles and boulders and 15 to 25 percent silt size particles. This soil geologically represents a glacial till. As classified by the U.S. Dept. of Agriculture Map, soils at the site belong to the Charlton Loam and Woodbridge Loam series. Both series are, as stated, derived from glacial tills.

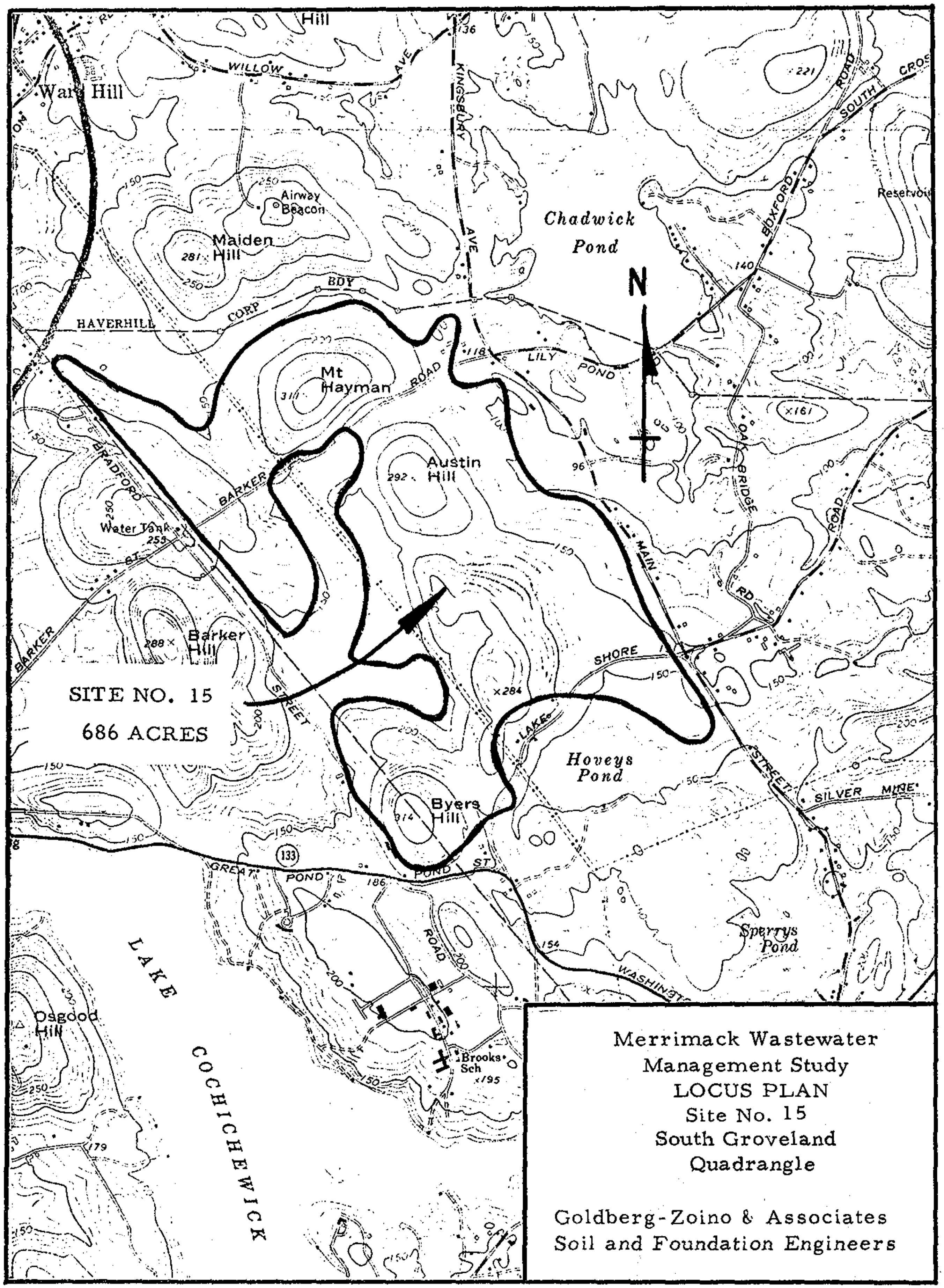
Much smaller portions of the site have been mapped as Merrimack fine Sandy Loam. These soils are reportedly developed from stratified glacial outwash materials. Their mapped location within the study area is limited to the eastern side, between Main Street and adjacent hills from Barker Road to Lake Shore Road. No direct evidence of these conditions was seen during our site examination. However, a heavy stand of White Pines was noted in this area. White pines also occurred in local patches elsewhere on the site, notably along the northwest slope of Byers Hill.

GROUNDWATER

Groundwater depths will vary seasonally. Side hill seeps occurred at several elevations, but their value in determining groundwater levels was minimal inasmuch as our site visit shortly followed a rainstorm. The position of the groundwater table would have to be determined by observation wells throughout the area, but for purposes of estimation, a depth of from 3 to 12 feet may be used.

EVALUATION OF SITE

The site would be of limited use for treating of wastewater. This opinion is based primarily on the topography of the area. Slopes in excess of 12 percent predominate, thus negating its value for overland runoff. Soil conditions probably limit its value for rapid infiltration in most areas, the possible exception being the previously described strip of land just west of Main Street. Saddles between the hills and lower hill slopes are currently farmed. The slopes in these rather limited portions of the site may prove to be acceptable for spray irrigation treatment.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 15
South Groveland
Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTE WATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #16

SITE LOCATION

The site is located within Dracut, Massachusetts approximately one-half to one mile north of the Town Hall. The site is bounded by Marsh Hill Road on the north, by Jones Avenue on the east, by Broadway (Route 113) on the southeast, by Fox Avenue on the southwest, and by Old Marsh Hill Road on the west. The site area encompasses about 720 acres as shown on the Locus Plan.

AVAILABLE DATA

The information available prior to our site visit consisted of the U.S.G.S. Lowell, Massachusetts-New Hampshire Topgraphic Map, 1966; the U.S. Department of Agriculture Soil Conservation Service Soil Map - Middlesex County, Massachusetts, 1924; Bedrock Geology Map of Massachusetts and Rhode Island, B.K. Emerson, 1916; and Plate 2 of Water Supply Paper 1669-Y Ground Water Resources of the Lowell Area, Massachusetts.

GENERAL SITE CONDITIONS

The principal site features consist of two drumlin-shaped hills locally called Marsh Hill on the west and Burns Hill on the east. The western portion of the site consists of open fields while the eastern portion of the site is moderately wooded. Slopes throughout the site are quite variable but generally do not exceed 16 percent; the steepest slopes existing on the northwestern flanks of Burns Hill and on the eastern flank of Marsh Hill. The top of Marsh Hill is relatively flat with slopes ranging from 2 to 4 percent. Many new residences are in evidence along the western site boundary and along a new residential road within the open field at the northwest site corner.

BEDROCK

According to the Geological Map by B.K. Emerson, principal bedrock types are the Dracut diorite at the Burns Hill area and Merrimack quartzite in the Marsh Hill area.

The Dracut diorite has been described by Emerson as follows: "moderately coarse grained biotitic granodiorite or quartz diorite, which generally contains subordinate augite or hypersthene and in many places some hornblende, and which shows a strong tendency toward a foliated or gneissic structures." Several outcrops of this formation were noted in the southeast corner of the site.

The Merrimack quartzite has been described by Emerson as: "The formation consists chiefly of thin-beddded quartzite or quartz schist, as a rule somewhat actinolitic"; "The rock is in general more massively quartzitic toward the northwest side of the belt and more slaty toward the southeast side, and seems to show a progressive increase in its slaty character northeastward along the strike."

The depth to bedrock varies throughout the site. In the Burns Hill area bedrock is shallow and outcrops are visible. However no outcrops were noted in the Marsh Hill area. Consequently bedrock may reach depths of 10 feet or more in this area.

SOILS

The soils throughout the site consist mostly of glacial till. Generally this formation consists of a brown fine sand and silt, little gravel and angular rock fragments. This till has been further characterized and sub-divided into the following categories by the Soil Conservation Service, the approximate percentage of each soil type being shown in the last column.

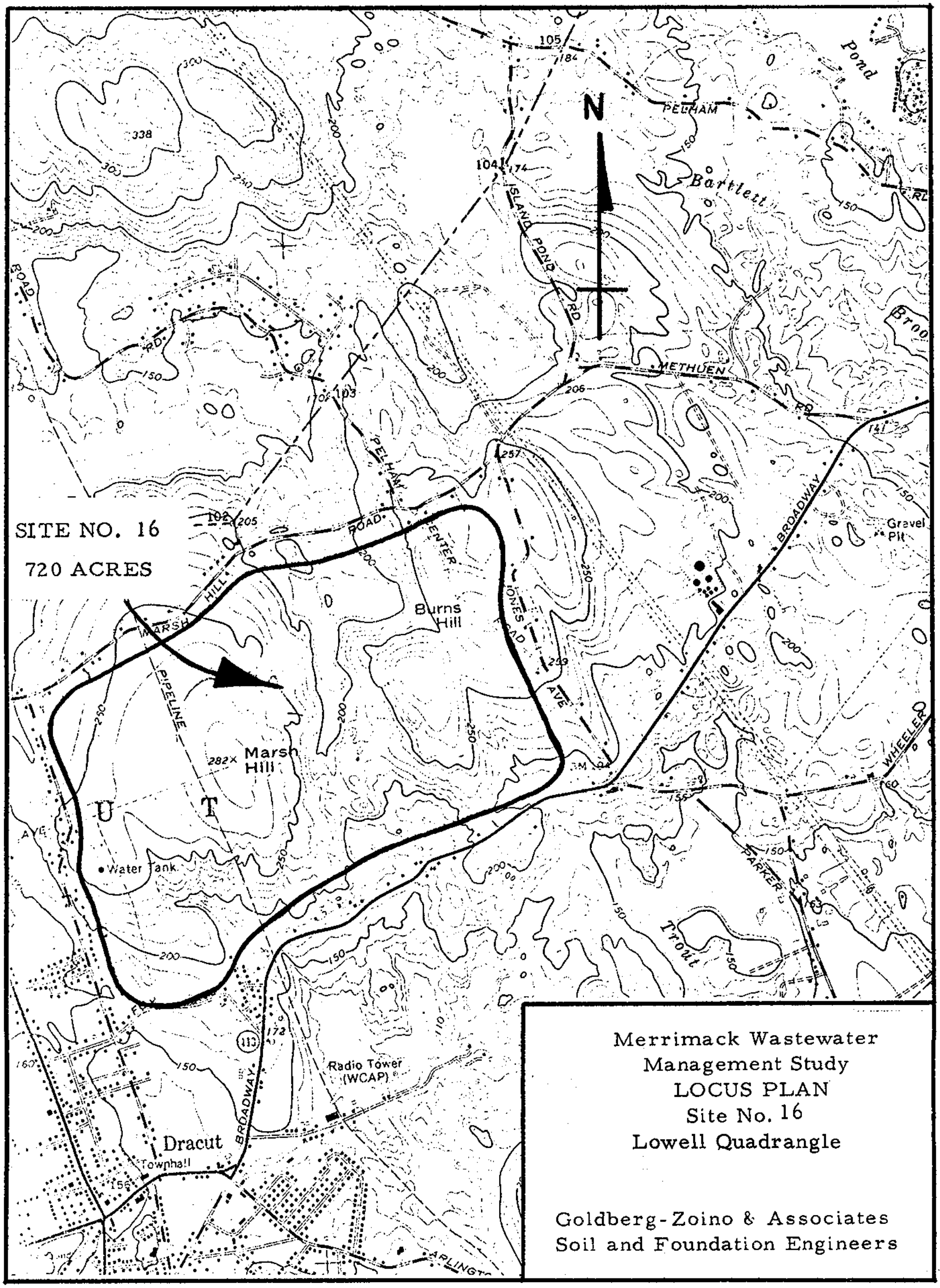
Symbol	Name	Soil Group	Approximate Percent
Gl	Gloucester loam	1	30%
Gt	Gloucester stony loam	1	30%
C	Coloma loam (also stony phase)	--	20%
W	Whitman stony loam	7	10%
M	Meadow	--	5%
Hs	Hinckley loamy sand	2	5%

GROUND WATER

Ground water throughout the site varies from ground surface in the low, wet areas between Marsh Hill and Burns Hill on the northern portion to somewhat deeper water conditions on Marsh Hill and Burns Hill. A typical range of expected ground water depth is between five feet and ten feet. This ground water table is expected to fluctuate throughout the year in accordance with seasonal phenomena. Consequently, the final assessment of the ground water regime would have to be based on ground water observation wells installed at the site and monitored over a period of time.

OVERALL EVALUATION OF THE SITE

The generally limiting features of the site may be described as glacial till with moderate slopes and a relatively high ground water table. Accordingly, wastewater treatment methodologies would be limited by these conditions. Rapid infiltration would be rather poor because of the relatively impervious soils and shallow depth to bedrock. Overland runoff would be rated poor to fair because of the moderate slopes. Spray irrigation would be rated fair to good because of the soil conditions and probable depths to bedrock and ground water. However, the degree to which the site would be suitable for spray irrigation would have to be based on further on-site explorations.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 16
Lowell Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTE WATER AND MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #17

SITE LOCATION

The site is located within the town of Concord, Massachusetts, northeast of the town center and northeast of an area well known in the annals of American history. The site is bounded by Monument Street on the West, by the Concord River on the east, and by Buttricks Road on the south. The site encompasses some 225 acres as shown on the accompanying Locus Plan.

AVAILABLE DATA

Prior to our site visit an office study was made of available information. This information consisted of : U.S.G.S. Topography Map; U.S.G.S. Surficial Geology Map of the Concord Quadrangle, Massachusetts by Carl Koteff; U.S. Department of Agriculture Soil Conservation Service Soil Map, Middlesex County, Massachusetts; and the Bedrock Geology Map of Massachusetts and Rhode Island by B.K. Emerson.

GENERAL SITE CONDITIONS

About 70 percent of the site consists of moderately to densely wooded areas and 30 percent of open areas. The northern portion of the site is moderately sloping land containing small rolling hills and meadow with slopes generally less than 8 percent except along the edge of terraced areas where slopes may approach 20 percent.

The southern portionof the site is dominated by Buttricks Hill. This is a small oval shaped hill approximately 50 feet high with slopes 15 to 20 percent on all sides. The flanking terrain to the north between Buttricks Hill and Balls Hill Road is a terrace-like formation with moderate slopes ranging from 8 to 15 percent.

The area has unique aesthetic qualities because of the nicely wooded character of the land particularly in the northern portion, and the fact that it abuts both a National Wildlife Refuge located to the east and the Old North Bridge historical site approximately one and one-half miles to the southwest.

BEDROCK

No bedrock outcrops were observed within the exposed portions of the sites. However, according to the bedrock geology map prepared by B.K. Emerson, the underlying rock consists of gneisses and schists of sedimentary origin and biotite gneiss of igneous origin. Both types are present in nearly equal amounts in this area. Based on visual observations at the site, depth to bedrock is estimated to be in excess of 20 to 30 feet. However the actual depth to bedrock and the character would have to be determined by test borings or geophysical methods.

SOILS

According to the surficial geology map by Carl Koteff, the site is underlain by glacio-fluvial deposits consisting of sand, gravel, and silt associated with glacial Lake Concord lower stage deposits. These soils consist of fairly pervious, well-drained, fine to coarse sands and fine gravels, with the exception of minor poorly drained lowlying areas generally occurring below elevation 130. According to the soil map of Middlesex County, the soil types at the site can be broken into the following groups and approximate percentages.

Symbol	Name	Soil Group	Approximate Percent of Site
G	Gloucester stony sandy loam	1	25%
H_s	Hinckley loamy sand	2	25%
M_s	Merrimack sandy loam	2	10%
H_g	Hinckley gravelly sandy loam	2	20%
M_p	Muck and peat	8	10%
M	Meadow	8	5%
G_s	Gloucester sandy loam	1	5%

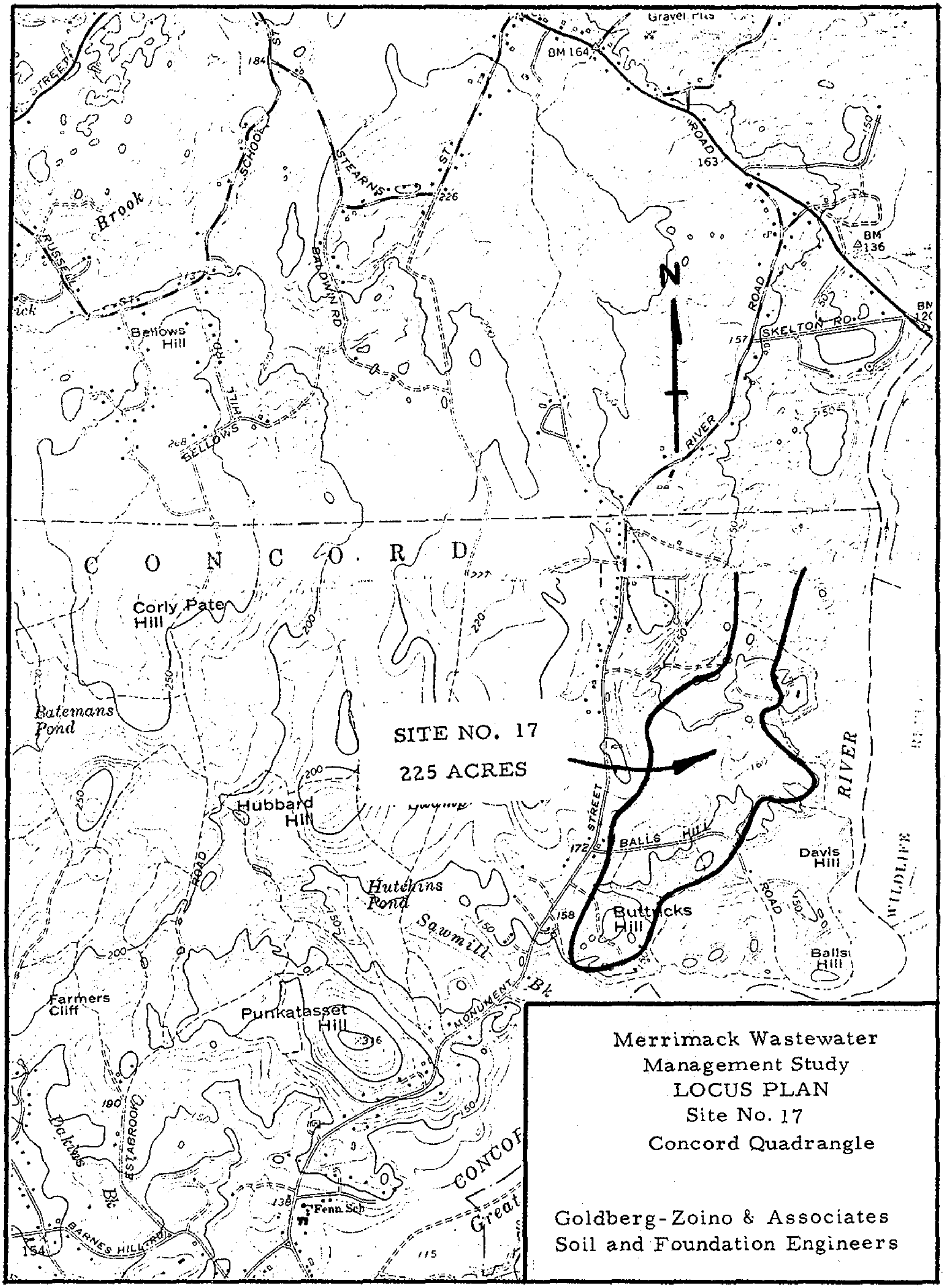
A soil sample was obtained for visual observation along the northeastern flank of Buttricks Hill within the area mapped as Merrimack sandy loam. This sample was a brown fine to coarse sand and fine gravel, trace silt.

GROUNDWATER

Groundwater was noted only in the lowlying area below elevation 130. Some high ground water may also be present in the northwestern portion of the site. However, the general appearance of the site is of being well-drained throughout with minor exceptions. The depth to ground water would have to be established by monitoring (over a reasonably long period of time) ground water observation wells throughout the area. However, based on an educated guess, ground water may be anticipated within depths of 10 to 20 feet below presently existing ground surface.

OVERALL EVALUATION OF THE SITE

Our general evaluation of the site is that it would have fair possibilities for waste water treatment, particularly for spray irrigation and rapid infiltration because of the relatively pervious nature of the upper soil. Overland runoff would probably not be a good possibility. The ground water conditions might limit use of the site for rapid infiltration. The site may have fair to good possibilities for spray irrigation treatment, however this possibility would have to be assessed further by detailed on-site studes including test pits and percolation tests. Other considerations such as historical, aesthetic, social and economic factors would in all probability have a bearing on this site because of its relation to the National Wildlife Refuge and the historical areas to the southwest.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 17
Concord Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTE WATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #18

SITE LOCATION

The site is located in the town of Concord, Massachusetts, adjacent to the town of Lincoln, Massachusetts. The site comprises some 500 acres. It is bounded by Route 2 on the north, by Walden Pond and the Walden Pond State Reservation on the northeast, by Fairhaven Bay on the south, and by the Sudbury River on the west. The site location is shown on the accompanying Locus Plan.

AVAILABLE DATA

Prior to our site visit an office study was made of available information. This information consisted of: U.S.G.S. Topography Map; U.S.G.S. Surficial Geology Map of the Concord Quadrangle, Massachusetts by Carl Koteff; U.S. Department of Agriculture Soil Conservation Service Soil Map, Middlesex County, Massachusetts; and the Bedrock Geology Map of Massachusetts and Rhode Island by B.K. Emerson.

GENERAL SITE CONDITIONS

The most prominent feature of the site is Fairhaven Hill which rises from relatively flat areas existing at elevation 200 to an elevation of 340 feet. The slopes on Fairhaven Hill vary from 20 to 30 percent. However there is a rather extensive, relatively flat-topped terrace-like formation to the east and south of Fairhaven Hill which has well-drained, relatively flat (slopes less than 8 percent) but somewhat hummocky terrain. Slopes of from 10 to 20 percent are evident along the edges of the terrace-like formation, particularly on the south near Fairhaven Bay.

The area appears to be well-drained and is densely to moderately wooded in approximately 90 percent of the area. A prominent bedrock outcrop occupies a large area on the south and southwestern flank of Fairhaven Hill. The area to the northeast of the railroad track which cuts the site is the Walden Pond State Reservation. This area, as well as the portion of the site south and east of Fairhaven Hill, has a high aesthetic value.

BEDROCK

The only area at the site where extensive bedrock deposits were noted was the extensive outcrop on the south and southwestern flank of Fairhaven Hill. This area exists as a massive outcrop of medium to coarse-grained granite. The bedrock is very hard and competent. According to B.K. Emerson this rock is part of the Andover granite formation. This formation consists of coarse porphyritic biotite-muscovite granite.

The depth to bedrock is expected to be variable throughout the site. Generally speaking, this would range from the previously mentioned outcrops to shallow bedrock (less than 10 feet deep) in the area of Fairhaven Hill. The bedrock may reach depths of 40 feet or more, particularly in the southern and eastern portions of the site.

SOILS

Soil formations at the site consist of glacial till throughout Fairhaven Hill and glacio-fluvial deposits in remaining areas. The glacial till is a poorly sorted unstratified mixture of sand, gravel, and boulders with minor amounts of clay and silt. The glacio-fluvial deposits, particularly along Walden Pond and in the southeastern portion of the site, appear as sand and gravel formations associated with Glacial Lake Sudbury.

According to the mapping by the Soil Conservation Service, the soil types existing at the site and the approximate percentage of each type are as follows:

Symbol	Name	Soil Group	Approximate Percent
M	Meadow	8	3%
M_s	Merrimack sandy loam	2	12%
Hg	Hinckley gravelly sandy loam	2	20%
Gd	Gloucester stony loamy sand	1	10%
H_s	Hinckley loamy sand	2	25%
M_c	Merrimack loamy sand	2	25%
R	Rough stony land	—	5%

With the exception of the bedrock areas and the areas of glacial till, the remaining portions of the site consist of fairly permeable well-drained sands and gravel.

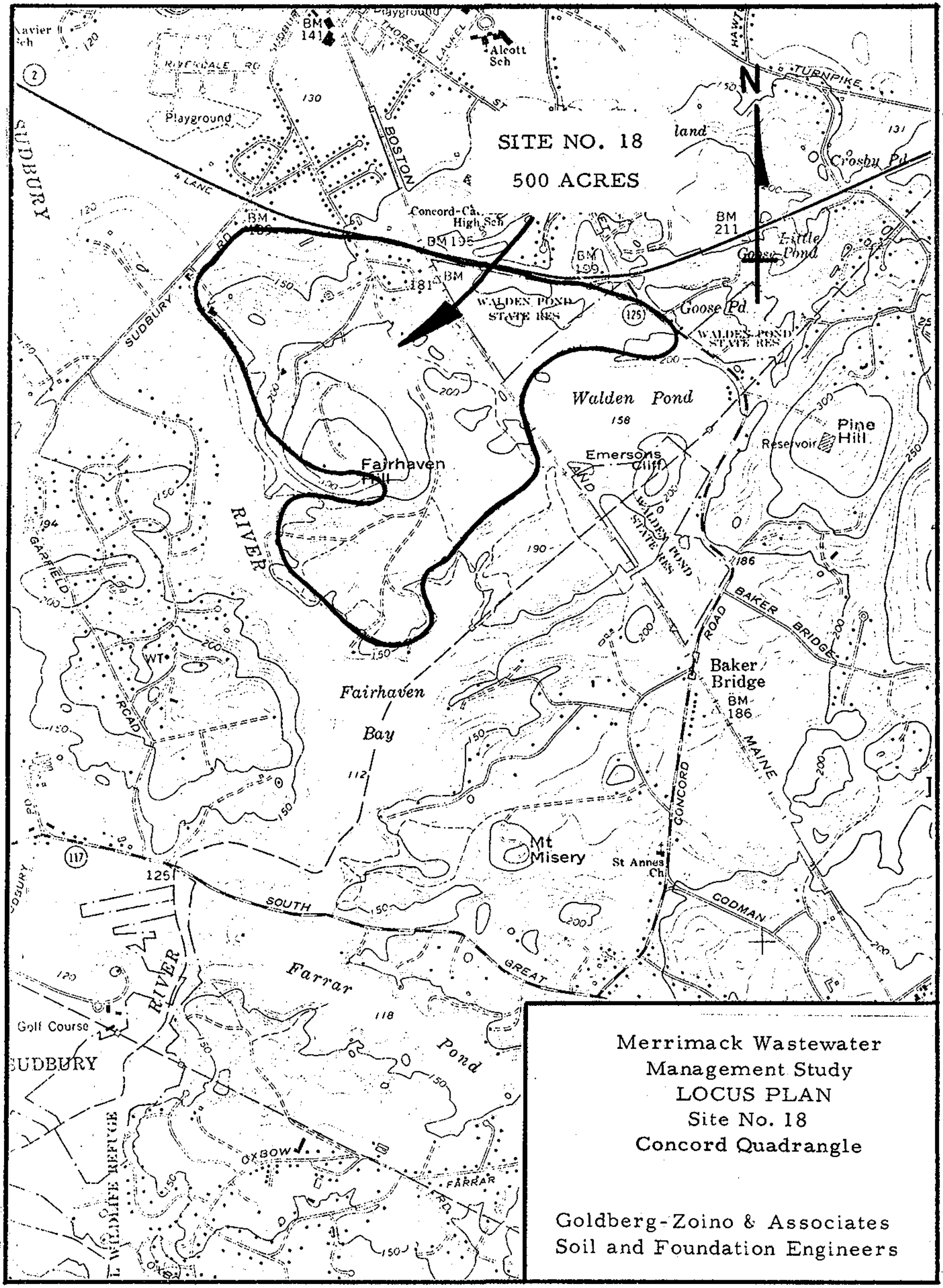
GROUND WATER

Ground water is expected to be shallow (less than 10 feet deep) in the area of glacial till but would probably be somewhat deeper (estimated 20 feet deep) in the sand and gravel formations.

A railroad cut occurring in the northeastern area of the site exhibits no ground water to depths in excess of 20 feet.

OVERALL EVALUATION OF SITE

The site appears to be well suited for use for waste water treatment, particularly of the spray irrigation type and possibly of the rapid infiltration type. The site does not appear to be well suited for overland runoff since the areas where soils are relatively impervious have slopes generally exceeding 20 percent. The overall rating of the site is good but final rating would have to be based on detailed on-site explorations including test borings and bore hole permeability tests before any final assessment could be made.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 18
Concord Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTE WATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #19

SITE LOCATION

The site lies on the Ashby-Townsend town line south of Massachusetts Route 119. The site is bounded on the north by Willard Brook, on the east by Pearl Hill Brook, on the south by Vinton Pond Road, and on the west by Fort Hill. The major portion of the site lies within the Willard Brook State Forest with minor privately owned parcels along the periphery on the north, east and south.

AVAILABLE DATA

Available information consisted of: U.S.G.S. Topographic Map - Ashby Quadrangle, 1965; Bedrock Geology Map for Massachusetts- B.K. Emerson, 1917; U.S. Department of Agriculture, S.C.S., Soil Survey of Middlesex County- W.J. Latimer and M.O. Lamphear, 1924.

GENERAL SITE CONDITIONS

The site encompasses approximately 650 acres as shown on the Locus Plan. The site is essentially heavily wooded with only minor cleared fields and open areas around dwellings. There is a hill (unnamed) in the north central section of the site rising to elevation 660 (MSL). To the west of this hill there is a saddle point at elevation 540 (approximate) and the land rises to elevation 750 (Fort Hill) further to the west. To the south and east of the central hill there is low undulating terrain ranging from elevation 350 to 450.

The surficial conditions vary over the site and for the sake of simplicity have been grouped into three zones as shown on the Locus Plan.

Zone I is comprised of the upper elevations of the central hill in the east plus the east slopes of Fort Hill. Exposed bedrock occurs on the easterly and southerly faces with a thin glacial till and soil mantle. The soil cover thickens on the westerly and northerly slopes and many large surface boulder are evident.

Vegetation consists of white birch, hemlock, maple, occasional white pine, white oak, and ash. Underbrush consists typically of mountain laurel in areas of hemlock. Underbrush is otherwise poorly developed. Slopes are irregular ranging from gentle to near vertical at outcrop faces. Average slopes range from 6 to 15 percent.

Zone II is comprised of the steep sloping face along the south bank of Willard Brook, typically between elevation 450 and 500 on the west (upstream) section and 400 and 500 in the east (downstream) section. A deeper glacial till is believed to occur in this zone and small surface boulders are common.

Vegetation consists principally of hemlock with mountain laurel underbrush. Minor numbers of small oak, birch, ash, and maple are also present. Slopes are more steep and more uniform, typically averaging 20 percent.

Zone III consists of the saddle area between the two hills and the lower undulating terrain south and east of the central hill. These areas are classified as kettle and kame topography and pitted outwash topography and consist of stratified, water-deposited sands and gravels. There are numerous dry kettles and kettle hole swamps throughout the area.

Vegetation consists principally of white oaks and white pine. A stand of red pine also occurs in the saddle area. Underbrush is poorly developed except in swampy areas where vines and briars are abundant. The slopes are highly irregular, ranging from steep to gentle; however the steep slopes do not cover large areas and the average slopes are typically less than 5 percent.

BEDROCK

There appear to be two types of bedrock underlying the site. The older rock type is the Worcester phyllite which outcrops south of the site and apparently forms a ridge beneath the site. The Worcester phyllite is also exposed along a highway cut on Route 119 north of the site at elevation 400 (approximate) and in this location it was intruded with igneous dikes. The more recent rock type is the Fitchburg granite and outcrops appear over the slopes and summits of the hills, typically above 450 on the east slopes of the central hill and above elevation 350 on the east slopes of Fort Hill. Boulders, but no outcrops, were observed on the west and north slopes of both hills. A predominant joint set dipping east approximately 70 to 80 degrees plus minor sheet jointing was observed.

The Fitchburg granite consists of medium grained light colored muscovite-biotite granite (Emerson). Samples taken in the field confirmed this. Outcrops are essentially massive.

SOIL CONDITIONS

Zone I

According to the Middlesex County Soil Survey, the soil profile is classified as Gloucester stony sandy loam in the central hill and Charlton stony sandy loam in Fort Hill. The Gloucester profile is developed in shallow to deep glacial till and the Charlton profile is developed in deep glacial till. Both are typically well-drained. From that it is inferred that the till is a "sandy" till, that is, a non-plastic mixture of sands and gravels with less than 25 percent silt

Ground water depths in Zone I are variable and will be controlled principally by the underlying bedrock.

Zone II

Soils in this zone are Gloucester stony sandy loam again indicating a sandy glacial till parent material. These soils are also well-drained but a high water table in wet seasons is believed to occur.

Ground water depths may vary from ground surface to many feet depending on the season.

Zone III

The soil profile in Zone III is variously classified as Merrimack gravelly loamy sand, Hinckley loamy sand plus muck and peat in low areas. These profiles are developed in glacio-fluvial or alluvial deposits. Examination of several open cuts within the zone indicated a poorly developed topsoil overlying stratified granular soils as follows: (See sketch for approximate locations.)

Location #1: Fine SAND and non-plastic SILT interbedded with fine SAND, trace Silt.

Location #2: Fine to medium SAND, trace Silt horizontally stratified with coarse Sand and fine Gravel.

Location #3: Fine to coarse SAND and fine to coarse GRAVEL (rounded), trace Silt.

Sample #4: Fine to medium SAND, little coarse Sand and fine Gravel horizontally stratified with coarse Sand, trace to little fine to medium Sand and non-plastic Silt, trace fine Sand.

Kettle holes which extend below the water table have filled with organic deposits which may reach significant depths depending on the size of the kettle hole. The thickness of the granular soils may be somewhat limited in the saddle areas especially at the narrowest points.

The ground water levels in Zone III will be controlled by the surrounding brooks, ponds, and kettle hole swamps. A relatively uniform gradient between Vinton Pond and Pearl Hill Brook may be reasonably postulated and little fluctuation in the ground water levels may be expected. The exception to this would be where the underlying glacial till rises abve the average ground water plane (especially along the contact with Zones I and II and in the saddle area). In these areas ground water would typically follow the surface of the glacial till in wet areas.

OVERALL EVALUATION OF SITE

By way of summary, the controlling features of the three zones are as follows:

Zone I- Glacial till over shallow bedrock, steep slopes.

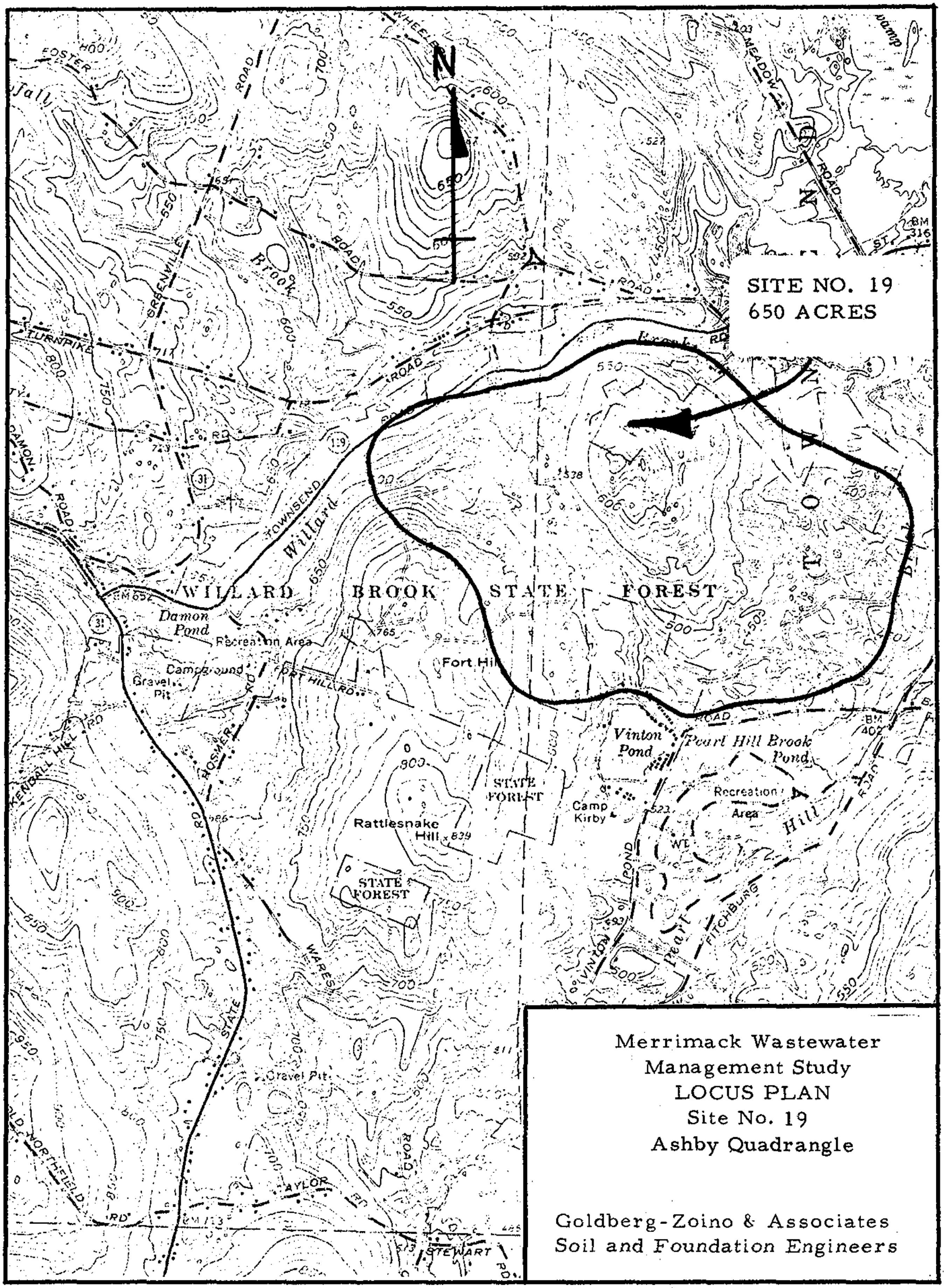
Zone II- Steep slopes, potentially high ground water; glacial till soils.

Zone III- Pervious soils, ground water may be locally shallow in topographic lows; variable topography.

Accordingly, the following evaluations are made with respect to methods of waste water treatment at this site:

Method	Zone I	Zone II	Zone III
Spray Irrigation	poor	no good	fair
Overland Runoff	no good	no good	no good
Rapid Infiltration	no good	no good	good

Rapid infiltration (Zone III) may require considerable earthwork. Limited areas of Zone I are suitable for spray irrigation and earthwork might enlarge the areas.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 19
Ashby Quadrangle

Goldberg-Zoino & Associates
Soil and Foundation Engineers

MERRIMACK WASTE WATER MANAGEMENT STUDY

INSPECTION AND EVALUATION OF SITE #20

SITE LOCATION

The site is located in the town of Wayland, Massachusetts. It is bounded on the north by Old Connecticut Path Road, on the east by Rice Road, on the west by Reeves Hill, and in the south by a swampy area associated with Snag Brook. The site area encompasses some 365 acres as shown on the Locus Plan.

AVAILABLE DATA

Prior to our on-site inspection available information concerning site characteristics was studied. These data included: U.S.G.S. Topography Map of the Natick Quadrangle; Preliminary Surficial Geology Map of Natick Quadrangle by Arthure E. Nelson, 1972; Soil Map of Middlesex County- U.S. Department of Agriculture Soil Conservation Service; Bedrock Geology Map of Massachusetts and Rhode Island by B.K. Emerson.

GENERAL SITE CONDITIONS

The site consists of a rather large hill both abutting and making up an integral part of Reeves Hill. Maximum relief throughout the area is approximately 200 feet. The site area is heavily wooded except in the northern portion which is open farm land. Slopes may be considered to be moderate to steep, generally in excess of 8 to 10 percent and often in the range of 25 percent, particularly along Reeves Hill. There are attractive residential areas of recent origin existing in the southeastern portion of the site off Reeves Hill Road. Many boulders and stone fences were noted throughout the area.

BEDROCK

According to the geological mapping of B.K. Emerson, the bedrock type is for the most part related to the Dedham granodiorite together with gneiss and schist of uncertain geological origin. According to Emerson, the Dedham granodiorite can be further described as follows: "In this group of intrusive rocks many types are represented, from quartz veins, pegmatite, and aplite, through binary granite and biotitic and hornblendic granites, syenites, tonalites, and diorites, to camptonite, gabbro, and dibase. Small masses of subsilicic rocks occur at some places, but their relations are not clear, and whether they should be grouped with the other rocks has not been satisfactorily determined. The most abundant and typical variety is a rather coarse biotitic granodiorite, composed essentially of microcline, plagioclase (generally andesine), quartz, and chlorite, and commonly more or less epidote and kaolin."

During the site examination several different rock types were observed and hand speciments were obtained. These hand specimens consisting of granodiorite, schist, pegmatite, and gneiss seem to cover the range of rock types suggested by Emerson. Concurrently, this variety of rock types gives the impression of a rather complex bedrock interrelationship in this area. Nevertheless, regardless of the details of bedrock origin, the rock appears in its exposed state as a very hard and competent crystalline rock.

Bedrock outcrops were numerous, particularly along the western portion of the site near Reeves Hill and also exposures along Rice Road in the northeast and southeast boundaries of the site. Based on these numerous bedrock exposures and also the large number of angular boulder fences, it is anticipated that bedrock is shallow throughout the entire area. Bedrock deposits in all probability range in depth from 0 to 10 feet in areas of visible outcrops to a maximum depth of perhaps 10 to 20 feet in areas where outcrops are not exposed.

SOILS

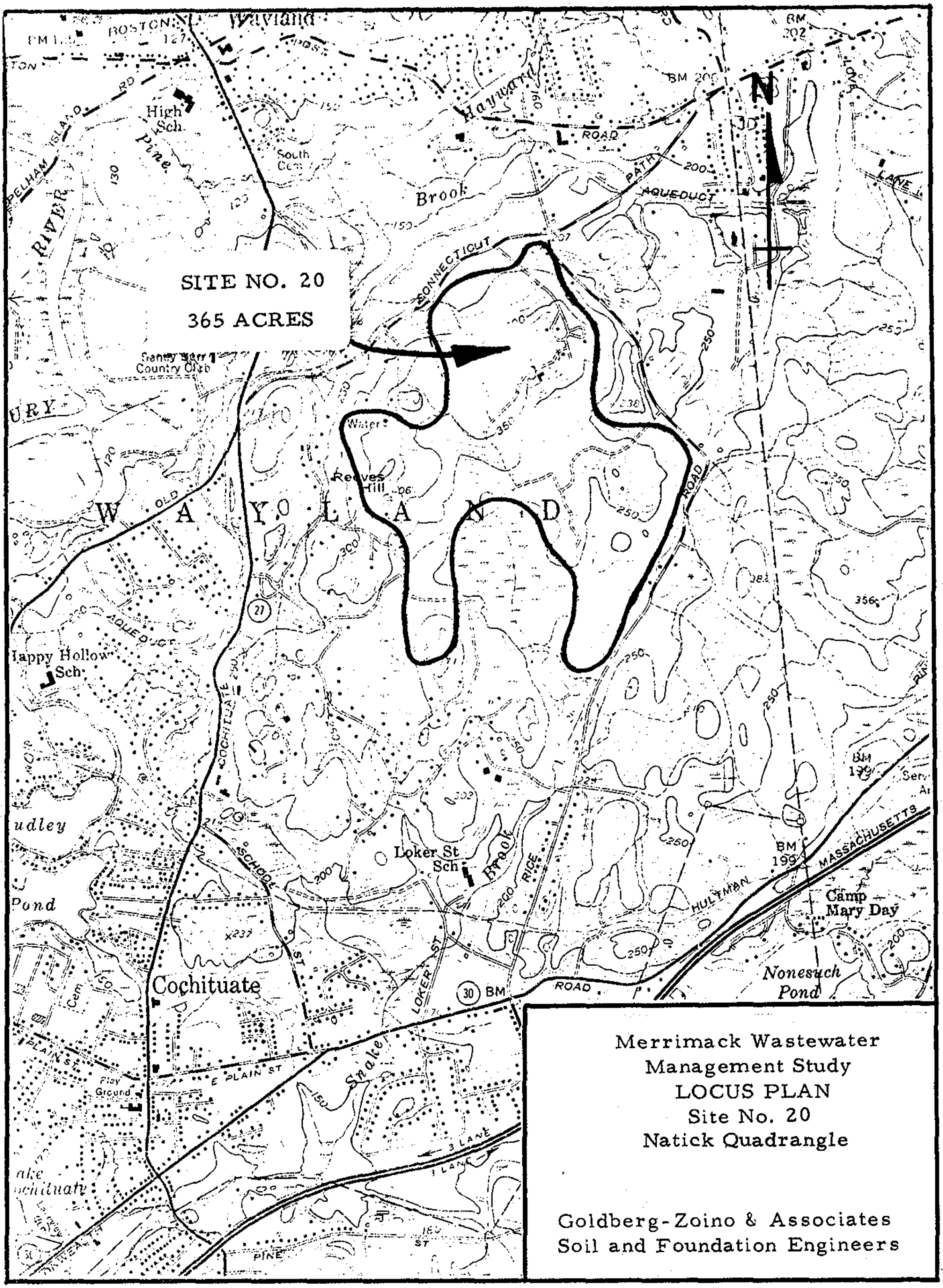
According to the preliminary surficial geology map, the major portion of the site is underlain by glacial till. This may be generally described as an unsorted mixture of fine sand, silt, gravel, and boulders and minor amounts of clay. A visual classification in a road cut adiacent to Reeves Hill indicated the soil to be a brown silt and fine sand, little angular gravel, and boulders. In another exposed shallow excavation for a new house on Reeves Hill, a granular lens consisting of fine to coarse sand and gravel, trace silt, was exposed. This situation may not be typical of the general area where the soil appears to be mostly a silty glacial till.

GROUNDWATER

The permeability of the soils at the site are believed to be low because of the relatively high percentage of this soil fraction which passes the No. 200 sieve. Ground water varies throughout the site but in all probability is controlled by the presence of bedrock (which is essentially impervious) and by the glacial till which would allow seasonal fluctuations. In general, it is anticipated that ground water would be encountered within the depths of 10 feet from existing ground surface. However a definite conclusion with respect to ground water could only be developed on the basis of monitoring ground water observation wells throughout the area over a period of at least one year.

OVERALL EVALUATION OF SITE

Based on the site examination and available data, the site is believed to be poor for use in treatment of waste water. In terms of usage for spray irrigation, it would have to be rated poor because of the relatively steep slopes and impervious soil conditions. The site would be rated very poor for use in rapid infiltration treatment because of the shallow depth of the bedrock and the relatively impervious nature of the glacial till. The site would also be rated poor for use of overland runoff because of the relatively steep slopes existing at the site.



Merrimack Wastewater
Management Study
LOCUS PLAN
Site No. 20
Natick Quadrangle

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